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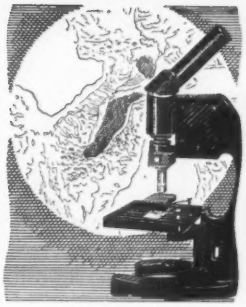

High-boron Alloy Steels

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SYNOPSIS

Before the advent of nuclear reactors little interest had been shown in boron alloy steels because the difficulties of working them were insurmountable and their extreme brittleness rendered them unsuitable for structural or engineering use. Since boron has a very high thermal neutron-capture cross-section, nuclear engineers became interested in using alloys containing substantial amounts of boron for 'control rods' and for general shielding duties in thermal nuclear reactors. This paper describes the discovery of a new technique for the production of boron–iron alloys containing up to about 4·75% boron which can be successfully forged, rolled, and extruded, and boron–iron alloys up to about 6% boron which can be successfully produced in the form of castings. The methods of manufacture, physical and mechanical properties, and constitution of these boron steels are described as well as their applications in thermal nuclear reactors. 1414

LITTLE INTEREST WAS SHOWN in iron–boron alloys containing appreciable amounts of boron before 1948 because it was known that these alloys were extremely brittle and they were believed to be unworkable. Consequently there appeared to be no commercial application of such alloys for structural or engineering components. However, in 1948 the Atomic Energy Research Establishment at Harwell indicated their requirements for the control rods of their first thermal nuclear reactor 'Bepo.' They required 2-in. dia. bar in an Fe–B alloy containing 2% boron, with carbon and other elements as low as possible, boron being required because of its high thermal neutron-arresting property. Hadfields' Research Department undertook the development of an alloy and succeeded in producing virtually pure Fe–B alloys with a maximum content of 2% boron which could be forged and subsequently rolled to 2 in. dia.

Nuclear engineers subsequently indicated that control rods should be produced from hollow Fe–B tubes about $1\frac{1}{2}$ in. o.d. and $1\frac{1}{8}$ in. i.d., with more than 2% boron. The tubes were preferably to be produced by forging and subsequent hot extrusion but if the higher-boron alloys proved unworkable then castings would be acceptable. It was soon found that above 2% boron, commercially pure Fe–B alloys were extremely difficult to forge and that although some small experimental 20-lb ingots could be hot-worked, production-scale ingots were mostly unforgeable. The specification demanded that these Fe–B boron alloys should be as pure as possible but, of course, in the melting of steel deoxidation is essential. It was agreed that aluminium was the only satisfactory deoxidant which could be tolerated in the alloys for nuclear control rods. Examination of those early experimental alloys revealed the important clue that the forgeable alloys contained residual Al whereas the unforgeable alloys were virtually without Al, these differences arising from variations in the melting and deoxidation practice. Further detailed investigation led to the important discovery that there is a critical range of Al content for each boron content above 2% up to about 4·75% within which these Fe–B alloys can be successfully forged and rolled. Above 4·75% boron these Fe–B–Al alloys are unforgeable, but castings have been successfully produced up to about 6% boron. The control rods for the first British atomic energy power station at Calder Hall were produced from extruded tubes of Fe–B alloys containing up to 3·8% boron and cast tubes containing up to 5% boron, from Hadfields' boron steels.

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* The boron steels described in this paper are the subjects of British patent applications and foreign patents.

PREVIOUS INVESTIGATIONS OF BORON-CONTAINING STEELS

From a search of the literature the authors have concluded that forgeable Fe–B alloys containing appreciable amounts of boron have not previously been produced and that they have received scant attention apart from the studies of the Fe–B phase diagram described below.

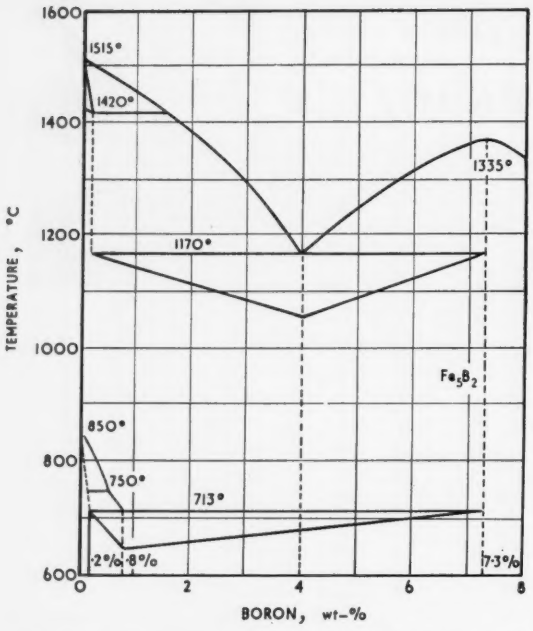


Fig. 1—Fe–B equilibrium diagram according to Hannesen

The most widespread use of boron in steel has been in the form of small additions made with the object of increasing the hardenability of medium- and high-carbon low-alloy steels, and a voluminous literature on this subject has appeared during the past decade.

Grossman[1] studied the effects of the addition of small amounts of boron to a steel of known hardenability, and found the effects on hardenability to be similar to those of other steel-alloying elements, but of much greater magnitude. The effects were noted with very small additions, the maximum benefit being derived from the addition of about 0·0025% boron. Corbett and Williams[2] showed a quantitative relationship between the influence of 0·003% boron and that of other elements on hardenability. The effect was shown to be 263 times that of nickel, 90 times that of chromium, 40 times that of manganese, and 77 times that of molybdenum. The function of boron is not agreed upon; Hollomon and Jaffe[3] have said that the effects upon hardenability depend to some extent on factors other than the amount of boron contained in the austenite.

McBride, Spretnak, and Speiser,[4] as a step in the elucidation of the boron-hardenability mechanism, determined the solubility of boron in γ- and α-iron and the effect of boron on the $\gamma \rightarrow \alpha$ transformation in iron. The solubility of boron in α-iron varies from 0·004% at 710° C to 0·0082% at 906° C. In γ-iron the solubility range is from 0·0021% at 906° C to 0·0210% at 1140° C. Whatever the mechanism of the influence of boron on hardenability, it is established that the addition of about 0·003% boron increases the hardenability of medium- and high-carbon low-alloy steels and additions of this order are made for the purpose of conservation of alloys, particularly in the U.S.A. The beneficial effects of such boron additions are confined to these steels in the hardened and tempered condition. The addition of 0·003% boron has no definite influence on the mechanical properties of mild steel, but Bardgett and Reeve[5] have shown that such an addition, in conjunction with 0·5% Mo, to mild steel raises the maximum stress from 28·5 to 41 tons/in^2, and the yield stress from 16·2 to 34·8 tons/in^2 with no loss in impact value, with normalized steel. The features of high yield strength and maximum stress in the conditions as-rolled or normalized, and the absence of serious hardening on rapid cooling make this steel useful for stressed welded structures.

Boron has been proposed as a precipitation-hardening element for addition to austenitic Cr–Ni steels, the hardening constituent being a boride–carbide solid solution. Wasmuht[6] found an increase in hardness from 240 to 430 Brinell on tempering steel containing 18% Cr, 8% Ni, and 1·1% boron for 8 hours at 800° C. Cornelius[7] concluded that in low-carbon austenitic steels, temper hardening was due solely to the formation of martensite, but with higher carbon true precipitation hardening may precede the martensite formation. Bennek and Schafmeister[8] found that with increase in hardness due to tempering of the boron-containing steel, toughness and corrosion resistance were adversely affected.

Small additions of boron of about 0·03% are also employed in the more advanced stainless ferritic heat-resisting steels.

Tschischewsky[9] noted a penetration of boron into soft iron, with the formation of a hard layer, when the iron was heated at 950° C in contact with amorphous boron or ferro-boron. Campbell and Fay[10] show that boron penetrates low-carbon steel much as does carbon under similar conditions, but boron-hardened steels show much difference in response to heat treatment, and are never as hard as with an equivalent quantity of carbon.

The uses of boron in iron and steel have been admirably summarized by Dean and Silkes.[11]

Iron–Boron Equilibrium Phase Diagram

The first investigation of the iron–boron system was made in 1914 by Hannesen[12] who determined the equilibrium diagram up to 8% boron (Fig. 1). A year later there appeared the work of Tschischewsky and Herdt[13] who presented a diagram up to 12% boron (Fig. 2). These diagrams are somewhat similar in essentials but differ in important details. For example Hannesen found a stable boride melting at 1350° C which he designated as Fe_5B_2, whereas Tschischewsky and Herdt found it to correspond to the formula Fe_2B with a melting point of 1325° C. They also differ appreciably in the degree of solid solubility.

In regard to equilibrium in the solid state, both workers agree in the following points (*a*) the solubility of boron in γ-iron increases with decreasing temperature, (*b*) the temperature of the $\gamma \rightarrow \alpha$ transformation is lowered by boron, (*c*) the eutectoid with respect to boron-saturated γ-phase decomposes into boride and α-iron. According to Hannesen the solubility of boron in γ-iron is about 0·8% boron at 713° C

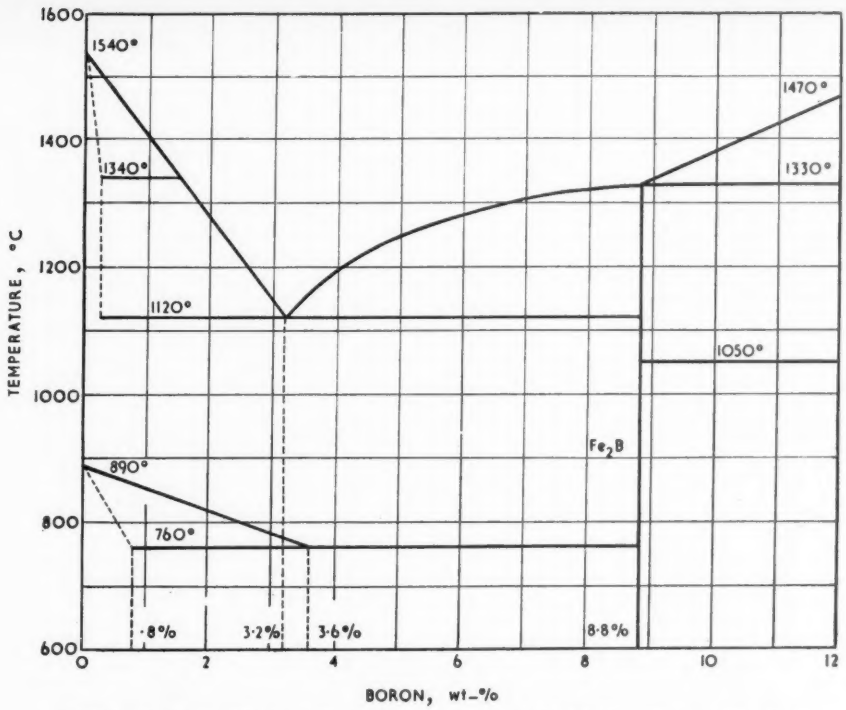


Fig. 2—Fe–B equilibrium diagram according to Tschischewsky and Herdt

whereas in the later diagram it is shown to be 3·6% boron at 760° C.

The Fe–B equilibrium diagrams determined by the above studies are similar to the Fe–C diagram. However, Wever and Mueller[14] questioned the results of the above two investigations on the grounds of appreciable contamination with carbon, Al, and Si, whose effects might outweigh that of boron. Wever and Mueller redetermined the Fe–B diagram employing alloys with relatively low carbon but still obtained some Si contamination and about 1·0% Al. In order to correct for the effects of these impurities, brief studies were made to determine the effects of Si and Al on the transformation points. They concluded that the effects of Al and Si were similar in that these elements restrict the γ-field by lowering A_4 and raising A_3 transformations. As a result of these studies the authors attempted to correct for the effects of Si and Al and extrapolated to what they term an 'idealistic' diagram reproduced in Fig. 3.

The solubility of boron as reported is very limited and is as follows: at 1381° C in δ-iron, 0·15%; at 1381° C in γ-iron, 0·10%; at 1174° C in γ-iron, <0·15%; at 915° C in γ-iron, 0·10%; based on X-ray results, the solubility of boron in α-iron is less than 0·15% at 915° C; at 880° C, 0·10%. The A_3 temperature is raised by 0·15% boron to 915° C and a peritectoid reaction is indicated at 915° C.

Although the work of Wever and Mueller[14] is accepted as the most reliable investigation of the Fe–B system forming the basis of the diagrams published by Parke[15] and Smithells,[16] it is subject to the major criticism that it has been deduced from impure Fe–B mixtures and can be accepted only as an approximation.

INFLUENCE OF ALUMINIUM ON HOT WORKABILITY OF IRON–BORON ALLOYS

For certain alloy steels hot compression tests have given a reliable indication of forgeability and of the optimum conditions for forging. As a preliminary to hot working on a larger scale such tests were made on a series of Fe–B steels. No attempt was made to maintain the temperature during the compression, which was applied on a falling temperature, finishing blackhot. Subsequent forging trials have shown that these tests were uninformative regarding actual forging, and so hot compression tests were discontinued.

A cone test has been suggested by Post, Schoffstahl, and Beaver[17] as a simple and effective means of determining forgeability. Under these conditions of testing, even those boron steels which experience has shown to hot-work relatively well fail badly and the test is not applicable to the present class of steels.

Apparently there is no simple test for the assessment of the hot workability of these boron steels and therefore it has been necessary to establish the hot working characteristics by the actual forging or rolling of the ingots and extrusion of billets on a production scale.

The initial forging experiments were carried out on a 2% boron alloy in the form of $2\frac{1}{4}$-in. square ingots. The published phase-diagram data indicated that the upper temperature limit would be lower than

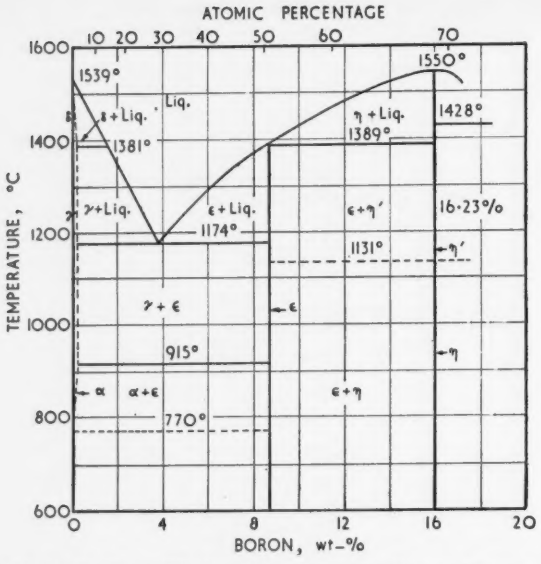


Fig. 3—Fe–B equilibrium diagram according to Wever and Mueller

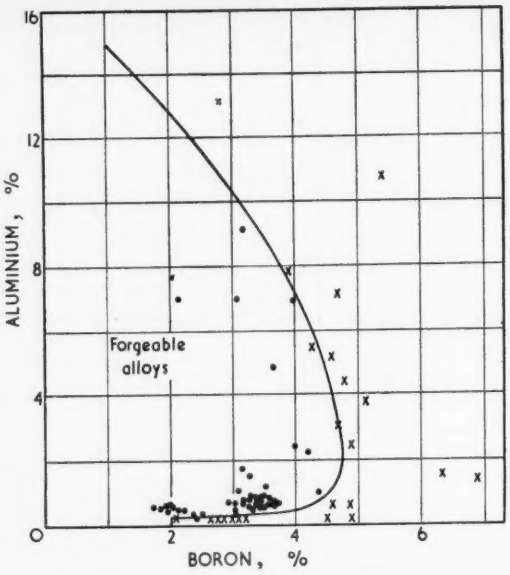


Fig. 4—Forgeability of B–Al steels

about 1100° C and in fact a temperature range of 1090–850° C was found to be satisfactory in practice. It was eventually found possible to forge and roll ingots of 2% boron steel in this temperature range up to 9 in. square. However above 2% boron, the Fe–B alloys proved to be unforgeable. Confirmation of the difficulty of hot-working iron–boron alloys is obtained from a recent publication[18] which describes laboratory-scale production of boron steels containing up to 3·34% boron, in which 1·5% boron was found to be the limiting content for successful rolling. However, it was found as a result of the present investigations that by the addition of Al to iron alloys the forgeable range could be extended up to about 4·75% boron. The influence of Al on the forgeability of these alloys (covered by British and foreign patents[19]) is illustrated in Fig. 4 which shows that for each boron content up to 4·75% there is an upper and lower critical Al content for forgeability; above 4·75% boron the alloys are unforgeable. In Fig. 4 the limit of forgeability for pure Fe–Al alloys is shown at 17% Al as found by Sykes and Bamfylde[20] in their study of the properties of Fe–Al alloys.

MELTING AND CASTING IRON–BORON ALLOYS

The alloys under discussion are essentially Fe–B alloys with boron in amounts up to about 6%, and with other elements, particularly those with a long half-life period, maintained at the lowest possible level.

Boron additions are made in the form of a ferro-boron alloy containing about 20% boron, produced by the aluminium reduction of boric and iron oxides. The production of a suitable grade of ferro-boron with the necessary low content of trace elements originally proved difficult, Mn in particular being troublesome. By selection of suitable grades of hematite ore low in Mn and other trace elements, satisfactory ferro-alloys were produced.

Preliminary small-scale melting in an induction furnace, using a base of Swedish iron, deoxidized before the addition of ferro-boron, gave a recovery of about 95% of the boron charged. In melting on a larger scale in a high-frequency induction furnace, contamination of the charge by Mn from the basic furnace lining was experienced. The lining was of magnesite bonded with a little basic slag, the reduction of the MnO in the slag being responsible for the contamination of the steel. Another objection to the

Table I

TYPICAL ANALYSES OF PRODUCTION-SCALE BORON STEELS

Steel No.	C	Si	Mn	B	Al
Cast steels					
1	0·16	0·23	0·13	4·05	0·03
2	0·09	0·38	0·21	4·14	0·12
3	0·10	0·43	0·14	4·20	0·53
4	0·11	0·45	0·18	4·25	0·03
5	0·10	0·44	0·23	4·29	0·35
6	0·09	0·52	0·19	4·30	0·02
7	0·11	0·42	0·23	4·40	0·10
8	0·15	0·43	0·21	4·42	0·05
9	0·08	0·46	0·27	4·58	0·11
10	0·12	0·60	0·31	5·03	0·29
Hot-worked steels					
11	0·04	0·20	0·10	1·75	0·54
12	0·07	0·47	0·26	1·85	0·04
13	0·10	0·62	0·26	1·90	0·02
14	0·05	0·70	0·30	1·96	0·03
15	0·05	0·48	0·13	2·20	0·44
16	0·07	0·75	0·40	2·64	0·21
17	0·06	0·31	0·49	3·15	1·75
18	0·08	0·46	0·24	3·24	0·89
19	0·11	0·48	0·30	3·40	0·61
20	0·09	0·53	0·26	3·62	0·76
21	0·11	0·56	0·29	3·62	0·76
22	0·10	0·52	0·27	3·69	0·76
23	0·11	0·48	0·30	3·79	0·61
24	0·09	0·53	0·26	3·81	0·71

use of basic linings also arises, for although the boron steels do not appear to be chemically reactive with them, they develop minute cracks, innocuous in almost all steel-melting practices but which are penetrated by the extremely fluid boron steels. For these reasons all subsequent melting of these boron steels has been carried out in acid-lined, high-frequency induction furnaces. On the larger production furnaces the boron yield is lower than that achieved in the small experimental furnace, being of the order of 85%. Remelting of boron-steel scrap shows the same order of recovery. The need for eliminating trace elements from these steels dictates the use of clean furnace linings, and to avoid contamination by boron of succeeding melts, the furnace must be 'washed out' after a run on boron steels. The ferro-boron rusts easily if stored in damp conditions, and can give rise to a very high hydrogen content in the steel. It should be dehydrated by roasting at about 800° C before use to minimize hydrogen absorption by the molten steel.

Ingots

Conventional iron moulds show a pronounced tendency to erosion by boron steels, even at the low casting temperatures which are allowed by the low liquidus temperature. Graphite moulds have been found to resist this erosion and have been successfully adopted for bulk production of these steels. The ingot skins are good, and machining before forging is usually unnecessary.

Table II

ANALYSIS OF STEELS USED FOR DETAILED MICRO AND DILATATION STUDIES

Steel No.	C	Si	Mn	B	Al
25	0·04	0·30	0·22	4·2	< 0·02
26	0·04	0·28	0·18	4·2	1·1
27	0·05	0·33	0·24	4·2	4·3
28	0·03	0·34	0·25	4·2	6·9
29	0·03	0·51	0·53	4·0	20·2
30	0·02	0·42	0·22	3·1	< 0·01
31	0·03	0·40	0·20	3·0	6·9
32	0·01	0·51	0·20	3·1	17·1

Castings

The boron steels react with most of the usual mould refractories. Zircon is less active, but the high rate of heat-absorption resulting from its thermal properties

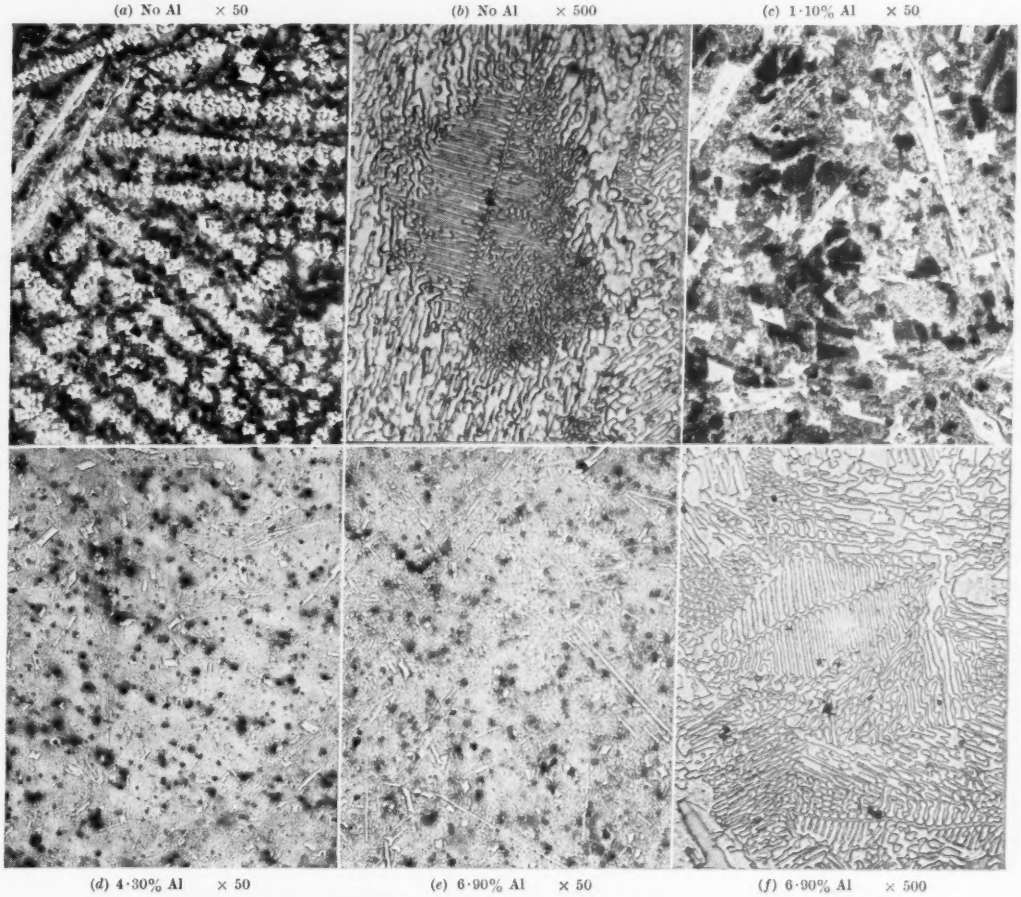
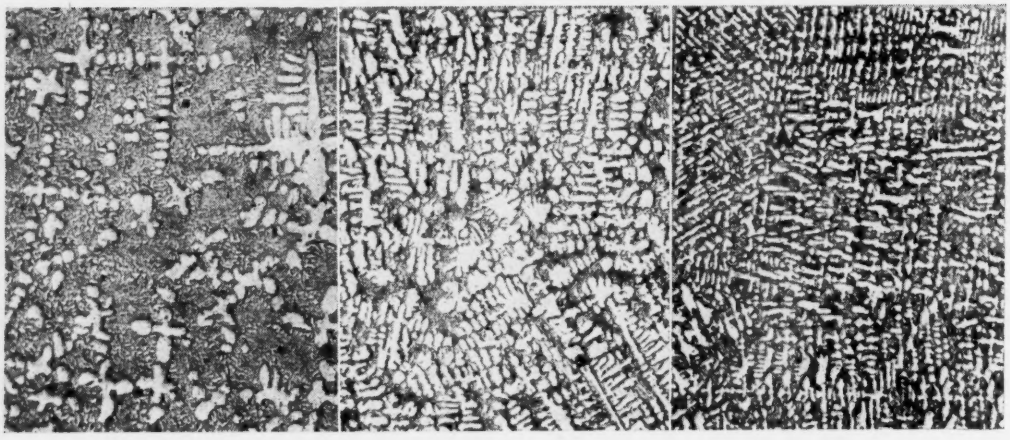


Fig. 5—Microstructure of 4·20% boron steels with varying Al content



(*a*) No Al (*b*) 6·9% Al (*c*) 17·1% Al

Fig. 6—Microstructures of 3% boron steels × 50

militates against the casting of thin sections. By strict control of the casting temperature, castings can be produced in silica-sand moulds; e.g. tubes with a wall thickness of $\frac{1}{4}$ in. are cast to a very high standard of dimensional tolerance and surface finish in resin-bonded silica moulds produced by the shell-moulding process. The steels are extremely fluid, and are successfully cast at temperatures near 1400° C.

WORKING BORON STEELS

Forging

The successful forging of boron steels containing up to about 4·75% boron treated with Al according to Fig. 4 has been achieved in the temperature range 1090–850° C, the largest ingot forged so far being 9 in. square. Steels with a maximum of 2% boron have been successfully forged from 14-in. square ingots. However, the boron content has been limited to 3·8% for large-scale production of steels for rolling or forging and subsequent extrusion into tubes. Typical compositions of these and also of cast boron steels are given in Table I.

It will be observed that carbon contents are preferably lower than 0·10% because it has been observed that, particularly with the higher boron contents, increasing carbon contents increase the difficulties of forging.

Any failure in forging is sudden; cracks, which in most steels could be removed, develop rapidly through the forging, so that the dividing line between complete success and failure is very sharp. These steels are brittle even at forging temperatures, and any tendency to bend under the hammer must be avoided by fully supporting the forging. Forging in swages is preferable and the force of the blow must be carefully controlled.

It should be emphasized that the term ' forgeable ' applied to boron steels does not indicate the normal forgeability of structural or low alloy steels. Close control of the operating temperatures is vital, the material being very prone to burn if heated much above 1100° C. During heating for forging, oxidation is appreciable and at 1100° C a fluid oxide is formed on the ingot surfaces. In addition the mode of deformation is critical, any break encountered in forging being extremely serious; these difficulties increase with increasing boron content. However, full yields in forging have been regularly obtained by strict adherence to the established technique.

Rolling

Boron steels which have proved to be forgeable can also be rolled in a temperature range rather lower than that used for forging, commencing at about 1050° C. A smooth passage through the rolls without mechanical shock is essential.

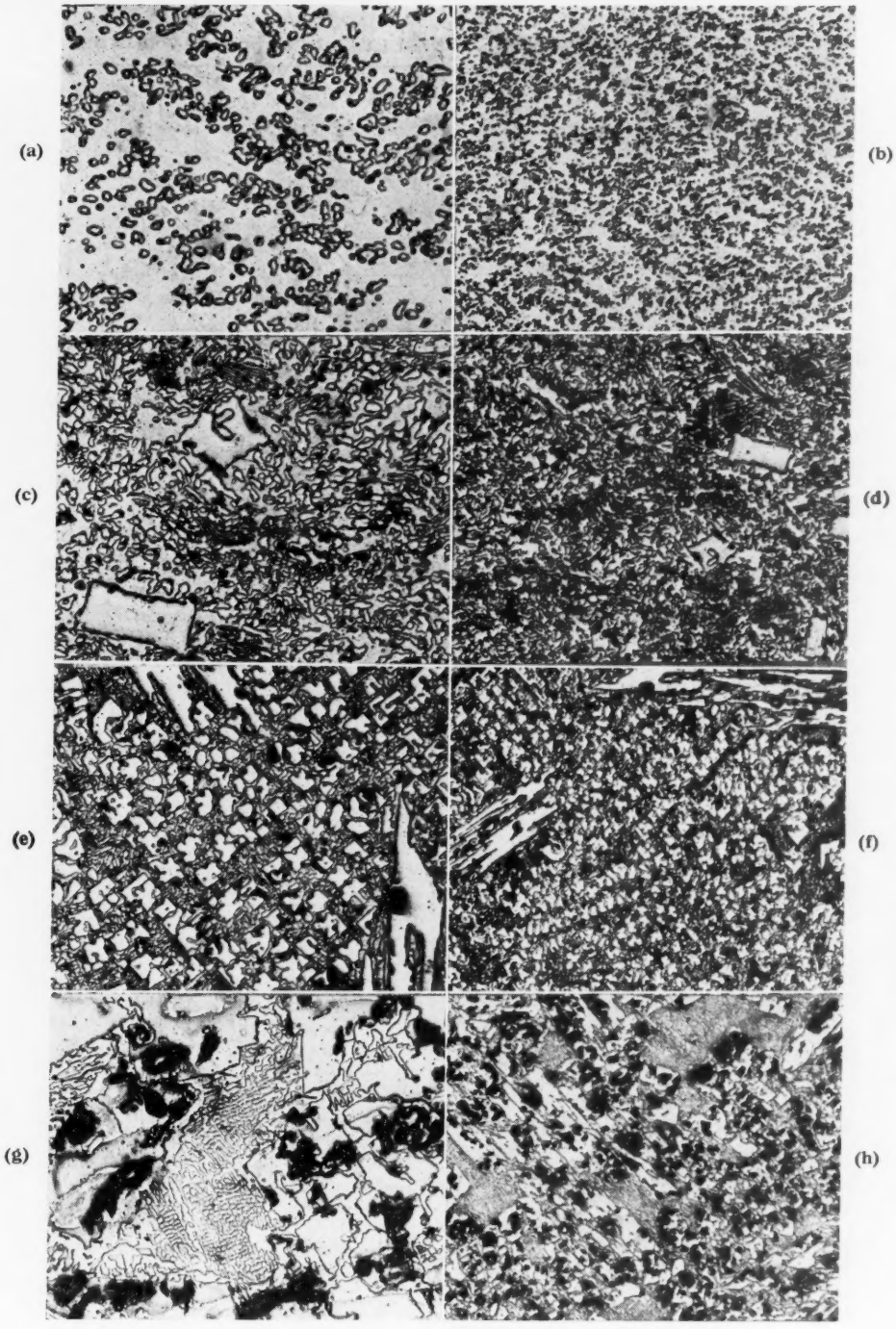
Extrusion

Large quantities of boron-steel tubes have been produced but the maximum boron content for successful extrusion is about 3·8%. Extrusion is carried out at the lowest temperatures (about 1000° C) compatible with adequate pressure on the extrusion press to give a smooth steady flow. Factors which are normally of minor importance in the extrusion of steels become important for boron steels; the mandrel temperature has a marked influence on the surface finish of the tube bore, and the speed of extrusion is about half that for stainless steel. Conventional lubricants on dies and mandrels are unsuitable, the

Table III

ANALYSIS OF STEELS USED FOR X-RAY CRYSTALLOGRAPHIC STUDIES

Steel No.	C	Si	Mn	B	Al
33	0·03	0·30	0·29	3·2	< 0·02
34	0·05	0·33	0·43	5·0	0·20
35	0·03	0·21	0·43	4·7	0·72
36	0·04	0·25	0·48	4·8	4·5
37	0·03	0·23	0·46	4·0	6·9
38	0·03	0·16	0·44	3·1	7·0
39	0·03	0·28	0·40	2·9	8·7
40	0·04	0·31	0·42	3·1	8·8
41	0·04	0·17	0·54	3·2	9·2
42	0·05	0·37	0·70	5·4	10·8
43	0·09	0·19	0·50	3·2	0·94
44	0·05	0·33	0·35	3·4	1·1



(*a*) Forged 2% boron × 250
(*b*) Forged 2% boron × 75
(*c*) Forged 3% boron × 250
(*d*) Forged 3% boron × 75
(*e*) Cast 4% boron × 250
(*f*) Cast 4% boron × 75
(*g*) Cast 5% boron × 250
(*h*) Cast 5% boron × 75

Fig. 7—Microstructures of annealed boron steels

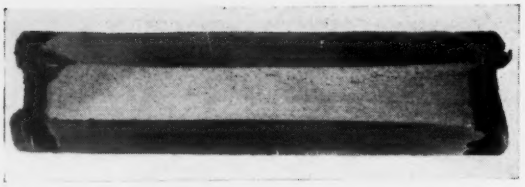


Fig. 8—Boron-mild-steel composite plate

best surface finishes result from the use of gas tar only. With meticulous attention to detail full extrusion yields have been obtained in production on all forgeable boron steels up to about 3·8% boron.

Machining

With boron contents up to 2%, the steels machine easily and similarly to cast iron. With increasing boron machining becomes more difficult until at 4% boron, carbide-tipped tools are essential. At 5% boron the steel is virtually unmachinable. These comments apply for turning, boring, milling, etc. but even at 3% boron the steels are difficult to saw.

CONSTITUTION OF BORON STEELS

Although the ternary Fe–B–Al phase diagram has not been investigated, the outstanding features of the constitution of the boron steels have been established by a combination of the available data on Fe–B[16] and Fe–Al[21] systems, and metallographic, dilatation, X-ray powder, and glancing-angle investigations.

Metallography

Series of cast steels containing either 3% or 4% boron (Table II) and increasing Al contents were thoroughly examined by metallographic techniques. In the absence of aluminium, these alloys represent the hypo- and hyper-eutectic conditions, respectively.

The metallographic features of cast boron steels are determined largely by the prominent eutectic in the binary Fe–B system, coupled with the acicular idiomorphism characteristic of the primary iron boride (Fe_2B) phase in hyper-eutectic alloys.

The microstructure of a cast alloy containing 4·20% boron and only 0·02% Al is illustrated in Fig. 5*a*. Two phases are present in this structure, a prominent dendritic network of primary iron boride and a matrix of eutectic of which the detail is revealed at a higher magnification in Fig. 5*b*. The regular dendritic pattern will be noticed and the effect of this hard and brittle network is that the alloy is unforgeable. Under conditions of equilibrium it would be expected to be marginally hyper-eutectic and the evident excess of primary iron boride is attributed to ' coring ' of the cast structure. Normally, the carbon content of these alloys is kept well below 0·1% and free carbides are not identifiable in the structure.

In the ternary Fe–B–Al alloys, a distinct and progressive alteration in microstructure attends the addition of Al to the simple binary Fe–B alloy. To facilitate comparison with Fig. 5*a* the succeeding photomicrographs (Figs. 5*c–f*) show the effect of adding Al to the same 4·20% boron base composition.

Table IV

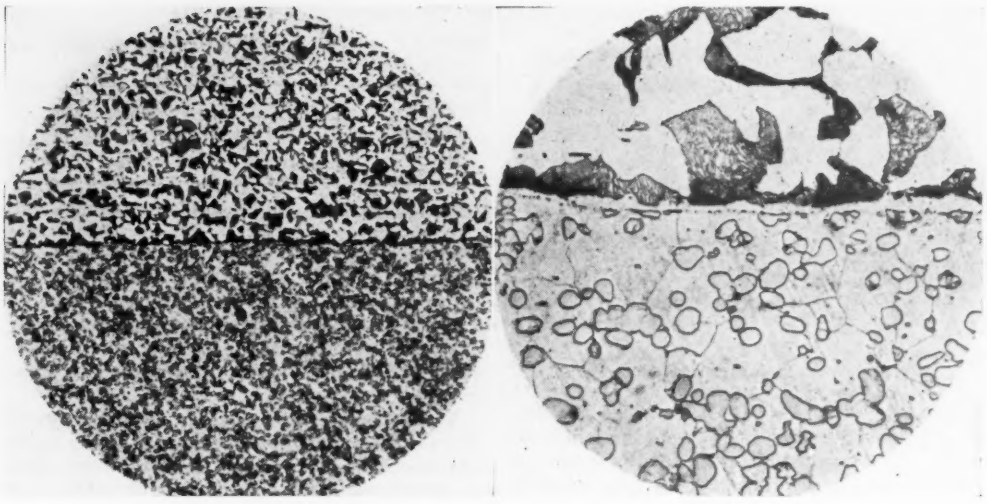
RESULTS OF 19-cm X-RAY POWDER DIAGRAMS

Steel No.	%B	%Al	a_0 Spacing of α-phase	Estimated Amount of Fe-B on Arbitrary Scale 1–7	Relative Crystal Size of Fe_2B Estimated by Line Profiles at High Angles
33	3·2	<0·02	2·865	2	Small
34	5·0	0·20	2·865	4	Fairly large
35	4·7	0·72	2·866	4	Large
36	4·8	4·5	2·887	6	Very large
37	4·0	6·9	2·889	1	Very small
38	3·1	7·0	2·889	2	Fairly large
39	2·9	8·7	2·889	1	Very small
40	3·1	8·8	2·890	2	Fairly large
41	3·2	9·2	2·901	2	Fairly large
42	5·4	10·8	2·886	7	Large
43	3·1	0·94	2·867	2	Small
44	3·4	1·1	2·868	3	Fairly large

Table V

PHYSICAL PROPERTIES OF BORON STEELS

Property	Boron Content		
	2%	3%	4%
Thermal expansion, in. × 10^{-6}/° C			
20–100° C	10·0	10·0	9·5
–200	11·0	10·3	10·0
–300	11·5	10·6	10·4
–400	11·9	10·9	10·8
–500	11·4	11·2	11·2
–600	11·8	11·5	11·6
–700	13·0	11·8	11·8
–800	13·3	12·0	12·0
–900	...	...	12·5
–1000	...	...	13·0
Electrical resistivity, μΩ/cm³			
0° C	24·9	37·2	39·9
26, 24·2,24	26·4	39·2	42·7
100	30·9	45·6	50·6
200	38·7	54·6	61·5
300	47·6	63·6	72·3
400	57·4	73·2	83·3
500	69·3	84·1	94·3
600	81·9	95·5	106·5
700	...	107·5	119·6
800	...	...	129·4
Specific magnetism S.C.I. = 100			
20° C	90·9	75·6	72·2
Specific gravity			
20° C	7·72	7·44	7·36
Specific heat, cal/g/°C	0·110	0·124	0·125
Thermal conductivity, c.g.s. units			
70–100° C	...	0·096	...



(*a*) × 100 (*b*) × 500

Fig. 9—Microstructure of junction of composite plate

An addition of 1% Al effects an immediate alteration in the microstructure, as shown in Fig. 5*c*. The prominently dendritic disposition of the primary iron-boride needles is disturbed, leading to a greater degree of continuity in the eutectic matrix. Significantly, the forgeability of this alloy is markedly superior to that of the simple binary alloy which is in practice unforgeable.

Continued additions of Al (4% Al in Fig. 5*d* and 7% in Fig. 5*e*) effect further breakdown of the dendritic characteristics, with a progressive refinement of the size and decrease in the amount of the primary iron-boride constituent. Relatively minor structural alterations in the matrix accompany these effects and the basic 'scroll' pattern of the eutectic remains unchanged, as may be seen by comparison of Figs. 5*b* and *f*. It is not entirely clear whether these effects arise from displacement of the eutectic composition or from an increase in solid solubility of the iron boride in the aluminium-rich matrix. The former explanation may however be favoured by a noticeable lack of structural response in alloys which have been annealed or quenched from a temperature of 1100° C. In association with this generalized structural refinement and increased continuity of the matrix, the forgeability of the alloys at first improves and then falls steadily until with about 7% Al in the 4% boron composition, the alloy again becomes practically unforgeable.

With continued additions of aluminium up to about 12% Al, the alloys appeared to approach more closely an eutectic composition and the inter-metallic component of this eutectic began to show a duplex response to etching, possibly signifying the introduction of an aluminium-rich phase. In none of these alloys were the grain boundaries revealed, even with recourse to specialized etching techniques. One is led to suspect from these observations that the ultimate stiffening of the alloys depends primarily on the approaching saturation of the matrix with dissolved Al, possibly in conformity with the observations by Sykes and Bamfylde[20] on binary Fe–Al alloys. Whilst the introduction of a specific aluminium-rich phase offers an explanation of the change in forgeability, it remains largely conjectural and the more probable role of Al in promoting an ordered matrix lattice would remain undetected by normal metallographic procedures.

The structural changes accompanying the addition of Al to the hypo-eutectic alloy again implied displacement of the eutectic composition to higher

Table VI

DROP TESTS ON BORON STEEL TUBES

Boron Content, %	Cast or Wrought	Height of Drop before Fracture, ft.
2	Cast and wrought	40 (unfractured)
3	Cast and wrought	40
4	Cast	20–30
5	Cast	10

Fig. 10—Bend test on composite plate

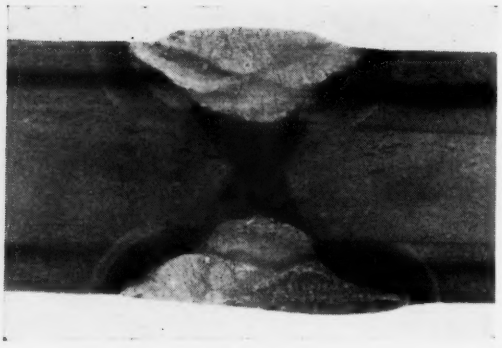


Fig. 11—Weld in composite plate

boron contents. A series of alloys based on 3% boron (*see* Table II) showed an eutectic matrix with increasingly prominent primary dendritic ferrite as the Al content increased; this change is illustrated in the photomicrographs of alloys with 0–17% Al in Figs. 6*a–c*. Once more, the most noticeable change on passing from an unforgeable to a forgeable alloy was the progressive subdivision and decrease in amount of the relatively hard phase, in this case the eutectic, of the duplex structure. Again, however, the ultimate decrease in forgeability which attended very large additions of Al was not accompanied by any outstanding metallographic alteration.

From a metallographic point of view, the results of heat treatment of these alloys were disappointing. After treatment at temperatures of up to 1100° C a slight granularity was apparent in the ferritic matrix but, with the exception of this small indication of solid solubility, the microstructures of both annealed and quenched alloys remained essentially unaltered.

Table VII

TENSILE TESTS ON COMPOSITE BORON STEEL PLATES

	tons/in²			
	Proof Stress			Breaking Stress
	0·05%	0·1%	0·2%	
Boron steel	19·8	21·0	22·0	38·4
Mild steel	18·4	20·7	22·5	

A similar indication of slight solid solubility was noticeable in alloys whose rate of solidification and cooling had been retarded by casting into a preheated mould.

A number of examples of photomicrographs of typical production forged and cast boron steels are reproduced in Figs. 7*a–h*. The structures consist of an eutectic of α-Fe and Fe_2B with either α-Fe or Fe_2B as the primary phase.

Microhardness of Constituents

Absolute values of the hardness of the respective constituents in the microstructures of boron steels are difficult to determine, but an indication of the relative hardness is given by microhardness determinations. In the case of the steel with 5% boron, hardness tests under a load of 50 g showed the eutectic matrix to have a hardness of 488–565 D.P.N. and the boride constituent 1524–1684 D.P.N. The hardness of elemental boron has been estimated as 2700–3200 (Knoop 10 kg load) and about 9·3 Moh scale.[22] These can only be taken as comparative values, but the presence of a very hard constituent in all the structures goes far to explain the difficulties in

Fig. 12—Forged billets for manufacture of extruded tubes

Fig. 13—Machined tube billets

hot working which are inherent in the higher-boron alloys.

Dilatation

The series of alloys shown in Table II have been examined by the dilatation method. These cast alloys were homogenized at 950° C in air before dilatation. On heating at a uniform rate of 5° C/min in a differential dilatometer the following points were established:

(i) In the aluminium-free alloy containing 4·20% boron the normal $\alpha \rightarrow \gamma$ transformation occurred in the range 840–980° C. There was also a slight contraction uniformly over the range 500–700° C

(ii) Addition of Al completely suppressed the $\alpha \rightarrow \gamma$ transformation in all the ternary alloys examined. The only dilatation change in the 1% Al alloy was a contraction in the range 500–700° C which was more marked than in (i)

(iii) The higher Al alloys showed a small expansion in the range 450–500° C followed by a slight contraction which was completed at 700° C. There was no trace of the $\alpha \rightarrow \gamma$ transformation

(iv) In addition a lower-boron alloy (3% boron, 7% Al) showed the same characteristics as the higher-boron alloy of the similar Al content described above.

It is suggested that the 500–700° C contraction found in all these alloys is due to change of solid solubility of Fe_2B in the ferrite solid solution, whilst the expansion in the higher Al alloys is due to the solution of Fe_3Al as indicated in the binary Al–Fe phase diagram.

X-ray Crystallographic Study of Boron Steels

A representative series of boron steels (Table III) was examined by the X-ray powder technique using a 19-cm camera. The detailed results are given in Table IV, and the following points were established:

(i) All the specimens consisted of two phases—iron boride (Fe-B) and a body-centred cubic phase (α-iron solid solution)

(ii) The cell dimensions of the Fe_2B phase remained constant throughout the series, indicating absence of solid solution, but the cell dimensions of the α-phase varied with composition, being always greater in the presence of Al than that of α-iron

(iii) According to the literature[23] Al dissolves in α-iron, expanding the lattice from 2·865 Å to about 2·890 Å at approximately 5% Al. Results shown in Table IV confirm that the lattice spacing increases with Al content to 2·890 Å at about 5% Al, the spacing remaining fairly constant with further increase of Al. Boron appears to have little effect on these spacing values. However, above 9% Al there are anomalous spacing values for α-iron solid solution which may be due to the formation of Fe_3Al

(iv) The amount of Fe_2B phase increases with increasing boron content, Al appearing to have little or no influence on the amount of free Fe_2B for a given boron content

(v) X-ray glancing-angle photographs of a further series of boron steels confirm that the alloys consist of α-iron, solid solution, and Fe_2B.

THE INFLUENCE OF ALUMINIUM ON CONSTITUTION AND FORGEABILITY OF IRON–BORON ALLOYS

The phase-diagram data, metallographic, dilatation, and X-ray studies are in agreement on the constitution of these alloys. In the absence of Al, the alloys consist of a eutectic of γ-Fe and Fe_2B in the forging temperature range, the primary phase depending on the boron content. Some alloys revert to α-Fe and Fe_2B on cooling to room temperature. These alloys are forgeable up to about 2% boron, being somewhat analogous to the Fe–C alloys in which the limit of forgeability is reached at about 2·5% carbon. It would appear that since the amounts of Fe_2B and Fe_3C at the limit of forgeability are somewhat similar there is a critical amount of hard particles which the γ-matrix can accommodate during forging.

Above 2% boron, sufficient Al is necessary to suppress the γ-phase to permit forging, the alloys consisting of α-Fe (with Al in solid solution) and

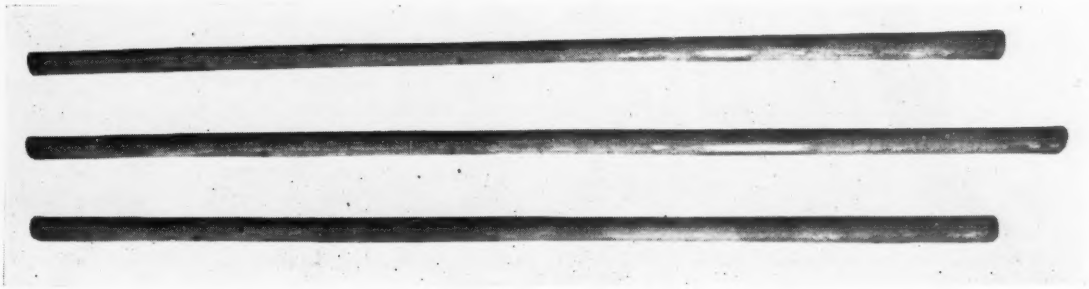


Fig. 14—Extruded tubes

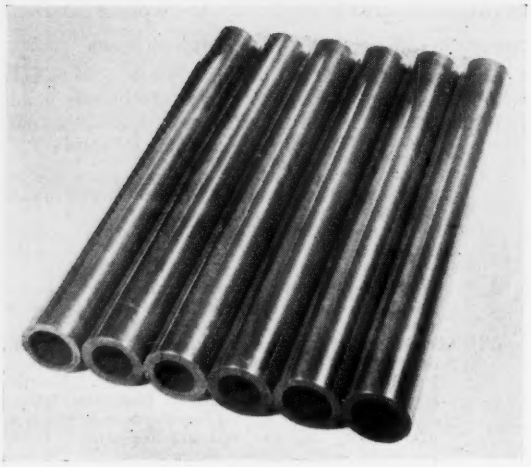


Fig. 15—Machined tubes

Fe_2B. The Al expands the α-Fe lattice and, according to Sykes and Bamfylde,[20] increases the ductility at forging temperatures. In addition the metallographic evidence shows that Al reduces the amount of large Fe_2B particles and refines the eutectic which will also assist forgeability. However, it is difficult to offer an explanation for the upper critical limit of Al for forgeability. Sykes and Bamfylde[20] found that for Fe-Al alloys the upper limit of forgeability was reached at about 17% Al without indicating the reason for this limit. Although there is no evidence to show that a third phase of the intermetallic or carbide type is present at the grain boundaries such an explanation would appear to be feasible, or it may be that at the higher Al contents the matrix loses ductility at forging temperatures. Further detailed investigations will be necessary to elucidate this feature of the B–Fe alloys.

PHYSICAL PROPERTIES OF BORON STEELS

The general physical properties of alloy steels with up to 4% boron are recorded in Table V.

Electrical resistivity and specific heat increase with increasing boron content, whilst density and magnetism decrease. Thermal conductivity for the 3% boron steel is lower than that of a boron-free steel, and is intermediate between mild steel and 12% Cr steel, representing either end of the ferritic steel series.

MECHANICAL PROPERTIES OF BORON STEELS

All the boron steels in the class under review are characterized by poor ductility and low impact properties. Tensile elongation of the 2% boron steel is only of the order of 3%, whilst with 3% boron or higher, less than 1% elongation is obtained in the tensile test. Because of this brittleness, the actual tensile stress figures are uninformative, but at 2% boron the maximum stress is about 45 tons/in², and for 3% about 55–65 tons/in². These limitations of mechanical strength impose the necessity for mechanical support where members are stressed in service. In the case of control rods the stress member is provided by an outer sheath of austenitic stainless steel which provides also protection from corrosion.

In view of the relatively poor mechanical characteristics of these steels, it was essential to devise some form of test to indicate their ability to withstand service conditions, and also as a quality control check. In service as control rods the only form of shock loading which is likely to be met results from an accidental vertical drop. Tubes 12 in. long with ends machined square were tested by dropping, with the axis vertical, on to a steel plate from successive heights of 10–40 ft in increments of 10 ft. Examples of the performance under these test conditions are given in Table VI.

Fracture of the tubes in this test is in the form of a clean transverse break. Enclosed in a stainless-steel tube, as they are in service, a fracture of this type does not reduce the effectiveness of the shielding.

Acceptance trials on the boron inserts for control rod service are designed on this basis and taken to the maximum drop which may inadvertently be sustained in service.

BRAZING AND WELDING

Boron steels may probably be required in structures too large for one-piece manufacture, and also for the

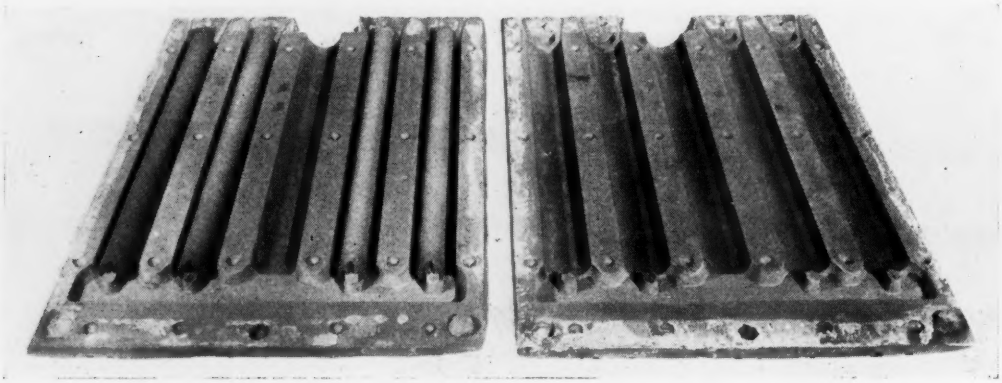


Fig. 16—Shell mould for cast tubes

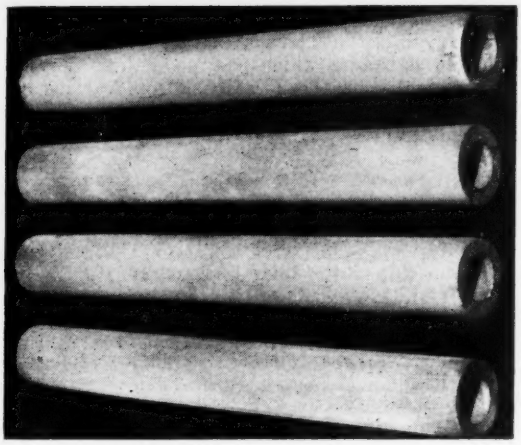


Fig. 17—Cast tubes

facing of structural and alloy steels with a neutron-absorbing shield. In other cases, protective coverings may be needed on the boron steels to avoid poisoning the reactor with boron. Where mild steel is used as the stress member to support the boron steel, adequate contact between the two to give good thermal conductivity through the structure may be needed. All such applications require brazing or welding, and where the temperature of operation is comparatively low, brazing may be adequate. Muffle-brazing trials, joining plates of mild steel and boron steel, using commercially available brazing alloys with melting points in the temperature range 650–850° C and the appropriate flux, gave good bonding, and indicated no difference in the brazing characteristics of the two steels. Shot blasting is as effective as machining for preparing the surface for brazing.

Where large areas of contact are concerned, brazing would be more difficult and less efficient. Another method of joining, applicable to such large areas, has been evolved, using plug welding. This method of providing a mechanical joint and maintaining continuity of heat transfer between the two metals depends upon the contraction during cooling of plug

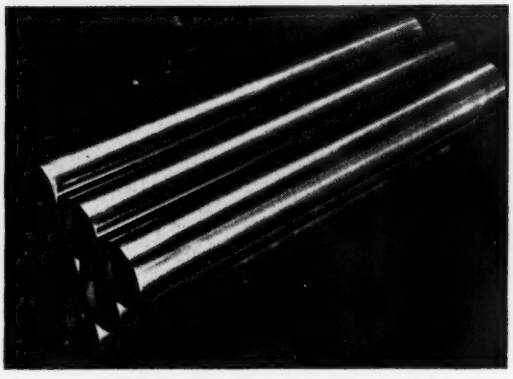


Fig. 18—Cast tubes after machining

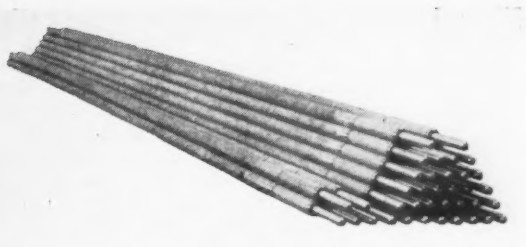


Fig. 19—Complete control rods

welds. The welds may be made from either the mild-steel side, using mild-steel electrodes, or from the boron-steel side using boron-steel electrodes. The insertion of copper foil between the plates assists in giving good contact over comparatively large areas. Arc welding of boron steels presents no difficulties, and they may be welded either to similar steels, mild steels, or austenitic alloy steels.

MANUFACTURE OF CLAD PLATES

An established method for producing composite plates is by solid-phase welding during rolling, oxidation of the contact faces between the respective metals being prevented by external welding around the joint edges of the preliminary slab. By this process, although the hot-working temperature range for the boron steels is limited and very different from that normally used for mild steel, clad structures of boron steel and mild steel can be made (Fig. 8).

Examples of one such type, in which 2% boron steel is clad on both sides with mild steel, may be mentioned. The composite billet consisted of a layer of the boron steel between two layers of mild steel. The contact faces were ground flat and thoroughly degreased, giving intimate metal-to-metal contact. The junction between the two steels was welded round the four edges to protect the contact faces against corrosion during heating and rolling. In rolling, the thickness was reduced to about one quarter of the original. Macroexamination showed a good junction between the two steels at both contact faces, as shown in Fig. 8, and microexamination indicated that welding had occurred between the boron and mild steels (Figs. 9*a* and *b*).

Tests on Composite Clad Plate

The composite plate, of $\frac{3}{4}$ in. total thickness, consisted of $\frac{3}{8}$ in. of boron steel with $\frac{3}{16}$ in. of mild steel on each side.

Longitudinal Bend Tests—(*a*) A sample was bent over a $\frac{1}{4}$-in. dia. former, between $1\frac{3}{4}$-in. centres, the angle of bend being 60°. At failure the boron steel fractured and the mild steel sheared on the tension side, with some separation of the two steels on the compression side of the boron steel. The surfaces in the separated zone confirmed that welding had occurred. The tested specimen is shown in Fig. 10.

(*b*) A sample was bent over a $1\frac{1}{2}$-in. dia. former between 5-in. centres, the angle of bend being 105°. Fracture was instantaneous through the boron steel and the mild steel on the tension side, with a slight

tendency to separation of the two steels close to the fracture on the compression side of the boron steel.

Strut Test—A bar, 8 in. long by 1 in. wide, was tested as a strut, and yielded at 16·5 tons. The first separation of boron and mild steels occured at 22 tons load, when the test piece bent to a radius of $8\frac{1}{4}$ in.

Tensile Test—This was made on a specimen cut from a similar plate, with electrical resistance strain gauges attached to both the boron steel and the mild steel. The proof-stress values in Table VII are those indicated for the respective steels on the basis of the stress on the full specimen.

Welding of Composite Plate

Any welding undertaken to join plates of this type would ideally require continuity of the structure to be maintained through the weld zone. Welding of the boron steel had already been shown to be feasible without any great difficulty, and attempts were made to produce welded joints with the central boron-steel deposit covered on either side by mild steel. Such welded joints are practicable, and the structure of one is illustrated in Fig. 11.

In making such a joint it is possible to ensure no penetration of boron from the central zone to the surface of the mild steel weld.

TYPICAL PRODUCTS MANUFACTURED FROM BORON STEELS

The development of the boron steels described in this paper was instigated to meet the requirements of the nuclear engineers in the construction of large-scale nuclear reactors. So far the commercial application of these alloys has been confined to the production of control rods, or plates for shielding purposes.

It has been found possible to make on a production scale billets, bars, and rods by forging and rolling and tubes by extrusion from boron alloys containing up to about 3·8% boron. Castings have also been produced in alloys containing up to about 6% boron. Plates up to 3 ft square have been produced on a large scale from alloys containing 2% boron, and clad plates appear to be a commercial proposition. The alloys can be machined with boron contents up to 5% and large quantities of intricately-shaped washers have been machined from 3% boron steel bars.

The original control rods were produced from 2% boron steel rolled bars but the modern control rods as used in Calder Hall have been constructed from 3·8% boron extruded tubes and 5% boron cast tubes, the higher boron content being preferred for lightness. The various stages of production of extruded and cast tubes are illustrated in Figs 12–18. The control rods (Fig. 19), consisting of machined, forged, and cast tubes inserted in a low-cobalt (0·01% maximum) austenitic, stainless-steel sheath, are operating successfully in the Calder Hall power station.

Acknowledgments

The authors' thanks are due to U.K.A.E.A. for their co-operation and continuing interest and for permission to publish the photograph of control rods as used at Calder Hall. The authors also wish to express their gratitude to the Chesterfield Tube Co., Ltd. for their valuable help and co-operation in the development of the extrusion process for boron steels. Valuable assistance which has made these developments possible has been received from various colleagues on the production and research staffs at Hadfields Ltd.

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Tin Research Institute

Open Days were held on 10th and 11th July at the laboratories of the International Tin Research Institute, Greenford, Middlesex, to celebrate 25 years of research. Techniques which have been developed or are in use at the Institute were on display; these include a wide range of coatings using tin and tin alloys. Valuable work on corrosion has also been carried out by the Institute. To commemorate the jubilee of the Institute, a booklet entitled "*Tin Research* 1932–1957" has been written by the Director, Dr. E. S. Hedges, which summarizes the notable achievements of the past 25 years.

Variations of Transformation Characteristics within Samples of an Alloy Steel

By

W. Steven, Ph.D., F.I.M., and D. R. Thorneycroft, B.Sc., A.I.M.

SYNOPSIS

Surveys have been made of the variations of isothermal transformation characteristics existing within unforged ingot samples and within 2-in. square bars produced from the same ingots. It is concluded that these variations, and the differences observed between the transformation characteristics of the ingot material and those of bars and wires derived from the ingots, are due largely to variations in the intensity of microsegregation of alloying elements within the different samples. 1310

SEVERAL INVESTIGATORS[1] have established the existence of longitudinal and transverse variations of hardenability within steel billets and bars of normal commercial quality. It has been shown[2, 3, 4] that in general the material near the axis of a rolled bar has lower hardenability than that near the surface, and that there is frequently a zone of peak hardenability at an intermediate position. It has also been demonstrated that the hardenability of the material near the axis and the position and magnitude of the zone of peak hardenability vary along the length of the bar, although the hardenability of the material near the surface has proved to be fairly uniform. Some variations of hardenability within steel bars are undoubtedly due to macrosegregation of carbon and alloying elements, but the papers presented in the Hardenability Symposium[1] demonstrate that the majority cannot be explained on this basis. The object of the present work was to assess in greater detail the extent to which longitudinal and transverse variations of hardenability occur within the wrought product of normal commercial ingots of medium-alloy steel, and to explain, if possible, the origin of the variations.

If there are variations of hardenability within a sample of steel, then it follows automatically that there will be variations in isothermal transformation characteristics. Thus, although the majority of previous investigators have used the end-quench test to explore this phenomenon in steel, it was decided in this investigation to study the extent of the variations of isothermal transformation characteristics.

The earlier stages of the investigation involved comparing the isothermal transformation characteristics of unforged ingot material with those of forged bar and wire samples derived from known ingot positions. The results obtained suggested that the hardenability variations were due to alloy segregation on a micro scale. The later stages of the work were therefore devoted to providing confirmatory evidence.

MATERIAL TESTED

Material from three $1\frac{1}{4}$-ton ingots of B.S.En 24 steel,* made in a basic electric-arc furnace, was used in the course of the investigation. Two of the ingots (Nos. 11 and 12) were from one cast of steel, but the third (No. 5) was from another cast. The analyses of the two casts involved are given in Table I.

The material available from ingots 5 and 12 included 6-in. thick unforged slices from the top and the bottom of each ingot, and 2-in. square bars rolled from material from the top, middle, and bottom of each ingot. Wires (9-gauge) representing the same ingot positions were also prepared from portions of the 2-in. square bars. The material available from ingot 11 included 6-in. thick unforged slices from the top, middle, and bottom of the ingot, 2-in. square bars forged from material taken from the top, middle, and bottom of the ingot, and 9-gauge wires derived from the same ingot positions.

9-gauge wires were included in the tests since wire of about this size has frequently been used in the U.K.[5, 6] for the determination of isothermal transformation diagrams.

EXPERIMENTAL PROCEDURE AND RESULTS

Part I—The Comparison of the Isothermal Transformation Characteristics of Ingot, Bar, and Wire Material, and a Consideration of Factors Promoting Variations

Transformation Characteristics of 9-gauge Wires

An isothermal transformation diagram was determined for each of the nine samples of wire representing the top, middle, and bottom of each of the three ingots. The dilatometric method was used to determine these diagrams, but in accordance with general practice the information obtained dilatometrically was supplemented by the results of microscopic tests. The austenitizing temperature used in these tests, and in all the transformation experiments described subsequently, was 835° C, and the austenitizing time was 30 min.

A typical diagram is shown in broken lines in Fig. 5 while the salient features of the nine diagrams are summarized in Table II. These show that the differences observed between the transformation times of wires from the top, middle, and bottom of any one

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The authors are with The Mond Nickel Co., Ltd.

Table I

CAST ANALYSES OF STEELS STUDIED

Cast no.	Ingot no.	Chemical composition, %							
		C	Si	Mn	S	P	Ni	Cr	Mo
36941	11 and 12	0·37	0·25	0·60	0·020	0·035	1·36	0·99	0·22
45695	5	0·38	0·20	0·60	0·019	0·030	1·35	0·99	0·24

of the three ingots were not great, the maximum difference between reaction times being about twofold. The maximum differences observed between the transformation times of the wires from the two ingots of the same cast were also about twofold. None of these differences was greater than those usually experienced in wire material.

Examination of the microstructures of longitudinal sections of partly transformed wire samples revealed, in general, little evidence of non-uniformity (Fig. 1) such as banding. Nevertheless, etch patterns, reminiscent of the hardenability patterns observed in large steel sections,[2] were developed by certain critical treatments in transverse sections of the wires. Those illustrated schematically in Fig. 2 were developed by heat-treating austenitized samples of the 9-gauge wire at 550° C for 24 h and then quenching to room temperature, the structures consisting of up to 10% bainite in martensite. It will be noted that the extent of the pattern increases progressively in size from the top to bottom ingot positions.

Although the patterns were fairly distinct when viewed on a macro scale, visual examination on a micro scale did not reveal differences between the degrees of transformation or between the transformation products in the different zones. Differences were observed, however, between the M_s temperatures of the materials of the two zones, as indicated by the values quoted in Table III. The material in the zone near the axis of each wire had a higher M_s temperature than that of the surrounding zone. The difference was generally slight, but in one case was as much as 25° C. Figure 3 illustrates the higher proportion of martensite developed at the axis of one of the samples during the early stages of transformation to martensite.

It appeared from the above tests that slight heterogeneity of chemical composition, possibly due to macrosegregation, was present in the wire, and that the zone affected varied in extent between the top and bottom ingot position. The effect of this inhomogeneity on the transformation characteristics of the wires was confined to the martensite transformation.

Transformation Characteristics of Unforged Ingot Material

Isothermal transformation diagrams were determined for both the columnar and the equiaxed zones of unforged slices from the top and bottom of ingot 5. The dilatometer test specimens used for this purpose were machined so that their axes were parallel to the ingot axis from the zones indicated by horizontal arrows in the photomacrographs of Fig. 4. Only one half of the ingot section is reproduced in this figure, as the macrostructure was symmetrical about the vertical centre-line.

One of the diagrams obtained is compared in Fig. 5 with that for 9-gauge wire produced from the same ingot position, and the salient features of the four diagrams for ingot material are summarized and compared with those for the corresponding wires in Table IV. These data show that in general the ingot material started to transform earlier and finished transforming later than wire material, the differences being greater for material from the equiaxed zone. The temperature range over which transformation to bainite was complete within about 24 h was narrower for ingot material than for wire material, being narrowest for material from the equiaxed zone.

Further exploration of the variation of transformation characteristics across the sections of the slices

Table II

SOME DETAILS OF ISOTHERMAL TRANSFORMATION CHARACTERISTICS OF 9-GAUGE WIRES

Ingot no.	Position in ingot	Pearlite reaction		Bainite reaction	
		Minimum incubation period, s	Minimum total reaction time, h	Minimum incubation period, s	Minimum total reaction time, h
5	Top	170 at 630° C	1·5	22 at 460° C	0·22
	Middle	90 at 620° C	1·2	20 at 480° C	0·22
	Bottom	140 at 640° C	1·1	20 at 480° C	0·16
11	Top	40 at 650° C	0·6	20 at 480° C	0·28
	Middle	25* at 650° C	0·5	20 at 460° C	0·14
	Bottom	40* at 650 °C	0·7	18 at 480° C	0·16
12	Top	48 at 630° C	0·6	25 at 440° C	0·33
	Middle	40* at 650° C	0·7	18 at 470° C	0·22
	Bottom	40* at 650° C	0·6	18 at 470° C	0·20

* Pearlite incubation periods of these wires were fairly constant over the temperature range 650–700° C, and the values quoted are those for the temperature of most rapid transformation.

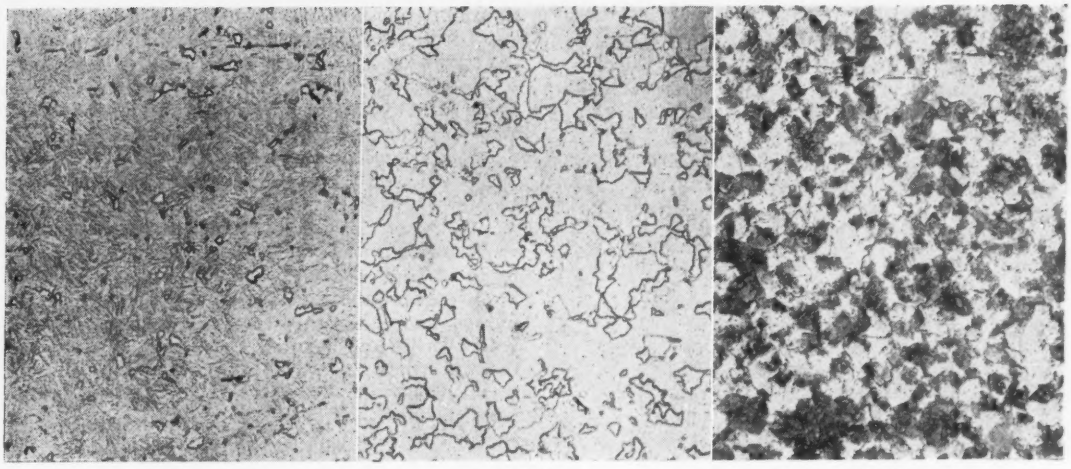


Fig. 1—Progress of transformation to pearlite at 640° C on 9-gauge wire from middle of ingot 5 (longitudinal sections) × 300

from ingot 5 was limited to comparisons of reaction curves for one temperature in the pearlite range (640° C) and one temperature in the bainite range (400° C). The positions relative to the macrostructure, from which the specimens were machined, are marked as *A*, *B*, *C*, *D*, etc. in Fig. 4. Typical reaction curves are compared in Fig. 6 with those of the 9-gauge wires from the corresponding ingot positions, and all the results obtained are summarized in Tables V and VI. These tabulated data further illustrate the differences between the transformation characteristics of ingot and wire material already revealed by the comparison of complete diagrams, and they are discussed below in some detail.

Table V shows that the pearlite incubation periods of the ingot samples from ingot 5 were up to eight times shorter than those of the wire samples. The bainite incubation periods of the ingot samples were equal to, or less than, those of the wire samples, the greatest difference being threefold. The time required for 50% transformation to pearlite was always shorter for ingot material, but the 50% bainite times of ingot and wire samples were approximately equal. The times required for complete transformation to pearlite of ingot samples from the top of ingot 5 (Table V) were up to 16 times longer than those of the corresponding wire sample. Pearlite formed less sluggishly, however, in the samples from the bottom of ingot 5, and the pearlite reaction times of these ingot samples exceeded those of the wire samples by factors of only about × 2. The bainite reaction times of the ingot samples from the top of ingot 5 were longer than those of the corresponding wire samples by factors of up to × 25, and the corresponding differences for the bottom of the ingot are represented by factors of up to × 10. All the ingot samples transformed completely to pearlite at 640° C but the degree of completion of

Table III

THE M_S TEMPERATURES OF THE 9-GAUGE WIRES FROM INGOTS 5, 11, AND 12

Origin of wire		M_S temperature, ° C		Difference in M_S temperature, ° C
Ingot no.	Position in ingot	Axial zone*	Surrounding zone*	
5	Top	325	315	10
	Middle	330	315	15
	Bottom	335	310	25
11	Top	325	320	5
	Middle	335	325	10
	Bottom	335	330	5
12	Top	325	320	5
	Middle	330	320	10
	Bottom	330	325	5

* see Fig. 3

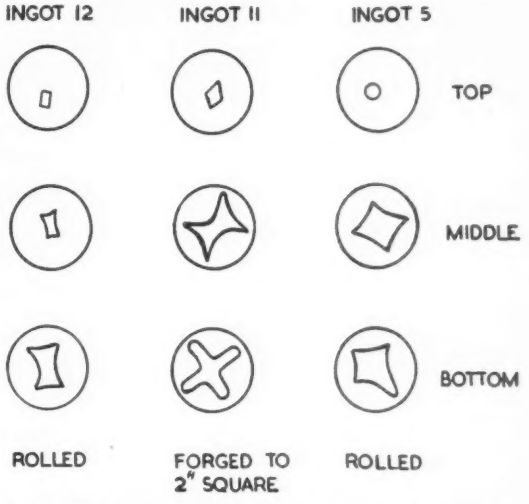
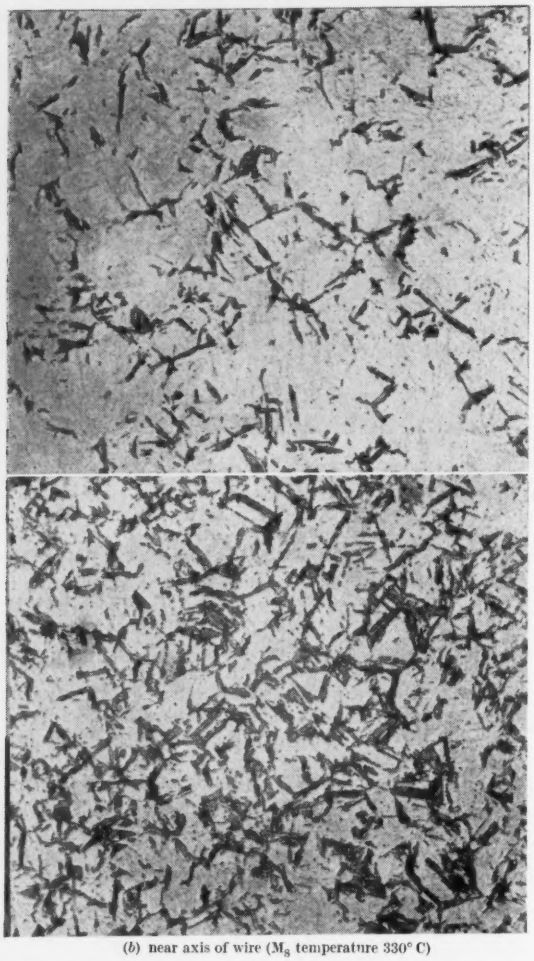


Fig. 2—Etch-patterns observed in the transverse sections of 9-gauge wires, partly transformed at 550° C

(*a*) near surface of wire (M_S temperature 325° C)



(*b*) near axis of wire (M_S temperature 330° C)

Fig. 3—Progress of martensite reaction at two positions in 9-gauge wire from the bottom of ingot 5 × 300

transformation achieved at 400° C decreased slightly but progressively from the surface to the axis of the ingot (Table V).

Similar trends are shown by the data presented in Table VI, in which are summarized the results of parallel tests on unforged material from ingot 12, but the differences between the corresponding reaction times of the ingot and wire samples from this ingot were generally smaller than those observed for ingot 5.

The pattern of the variations of transformation characteristics across the ingots is not well defined by the data of Tables V and VI. There is evidence, however, that the equiaxed zone of the ingot transformed more sluggishly than the columnar zone to both pearlite and bainite. There are also indications of peak pearlitic incubation periods, the values of which almost equalled those for wire, for material at positions intermediate between the ingot axis and surface. The test positions were not spaced closely enough to define the positions of these peaks exactly but, as far as could be judged from the available data, they were situated in the columnar zones at the bottoms of ingots 5 and 12 and in the outer region of the equiaxed zones at the tops of the ingots.

It was clear that considerable differences existed between the transformation characteristics of the ingot and wire samples, and that the variation arose almost entirely within the unforged ingot material. The incidence of these variations was next studied in bar material.

Transformation Characteristics of 2-in. Square Bars

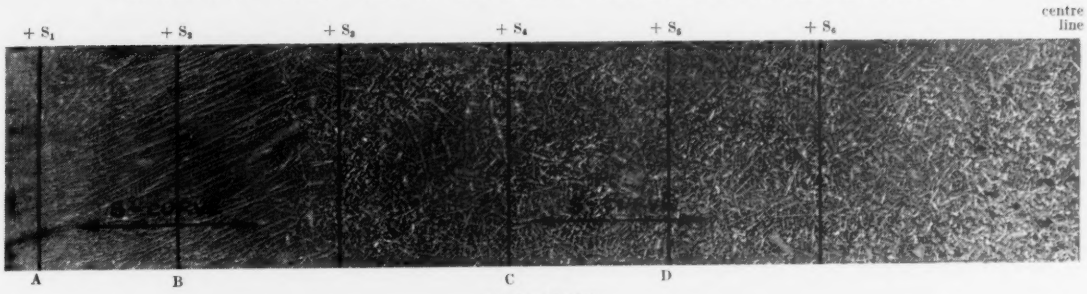
Complete isothermal transformation diagrams were not determined for the 2-in. square bars, but reaction curves for 640° C and 400° C were obtained for samples machined from selected positions in the bars of this size produced from ingot 5. The salient features of these are compared with those for the corresponding curves for ingot and wire samples in Tables VII and VIII.

It is apparent that certain of the transformation characteristics of the ingot material were affected by the hot reduction to 2-in. square bar. Thus the pearlite

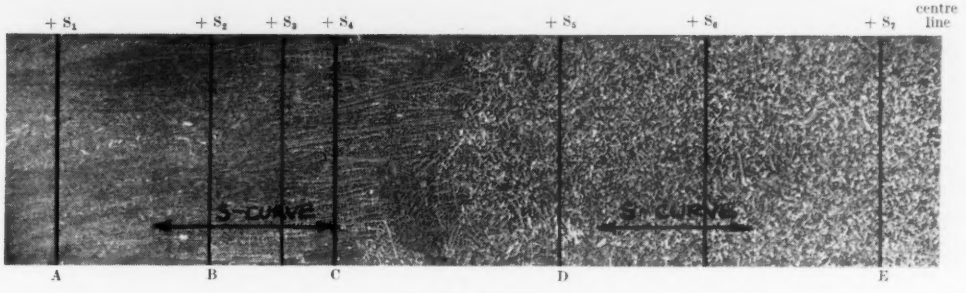
Table IV

TRANSFORMATION CHARACTERISTICS OF UNFORGED MATERIAL FROM INGOT 5

Sample	Position	Pearlite transformation		Bainite transformation		Maximum temperature for 100% bainite, B_f, °C
		Minimum incubation period, s	Minimum total reaction time, h	Minimum incubation period, s	Minimum total reaction time, h	
	Top					
Ingot	Columnar zone	50 at 610° C	14·0	10 at 440° C	0·28	390
	Equiaxed zone	10 at 600° C	14·0	10 at 500° C	0·36	390
Wire		170 at 630° C	1·5	22 at 460° C	0·22	460
	Bottom					
Ingot	Columnar zone	120 at 650° C	2·5	20 at 440° C	0·28	400
	Equiaxed zone	60 at 640° C	2·8	9 at 480° C	1·40	350
Wire		140 at 640° C	1·2	20 at 480° C	0·16	450



(*a*) Top of ingot



(*b*) Bottom of ingot

Fig. 4—Macrostructures of test slices from one half of ingot 5 (cast 45695). Letters A, B, C, etc., indicate position of dilatation test pieces, letters S_1, S_2, S_3, etc., indicate position of chemical and spectrographic analyses × 1 approx

Table V

THE PEARLITE AND BAINITE TRANSFORMATION CHARACTERISTICS OF INGOT AND WIRE SAMPLES FROM THE TOP AND BOTTOM OF INGOT 5

Position in ingot	Transformation temperature, °C	Incubation period, s	Time to 50% transformation, min	Time to end of transformation, h	Extent of transformation, %	Hardness, D.P.N.
Top						
Columnar zone, Position A	640	32	23	1·40	100	208
,, ,, ,, B	,,	60	30	4·20	100	210
Equiaxed zone, ,, C	,,	120	32	22·06	100	208
,, ,, ,, D	,,	30	27	19·50	100	213
Sample machined from wire	,,	150	42	1·40	100	207
Columnar zone, Position A	400	15	1·4	0·17	95	351
,, ,, ,, B	,,	15	1·6	0·22	90	351
Equiaxed zone, ,, C	,,	22	2·0	1·40	85	358
,, ,, ,, D	,,	30	2·3	5·50	85	345
Sample machined from wire	,,	34	1·8	0·22	100	363
Bottom						
Columnar zone, Position A	640	30	29	2·20	100	217
,, ,, ,, B	,,	150	24	2·20	100	224
,, ,, ,, C	,,	180	33	2·50	100	227
Equiaxed zone, ,, D	,,	60	22	3·60	100	208
,, ,, ,, E	,,	27	16	3·30	100	203
Sample machined from wire	,,	210	38	1·40	100	213
Columnar zone, Position A	400	30	1·7	0·25	90	360
,, ,, ,, B	,,	20	2·2	0·55	90	370
,, ,, ,, C	,,	30	2·2	0·55	85–90	362
Equiaxed zone ,, D	,,	20	1·7	1·40	85	365
,, ,, ,, E	,,	10	1·3	0·55	85	359
Sample machined from wire	,,	30	1·6	0·13	100	361

incubation periods of the bar material were, on average, longer than those of the corresponding ingot material and closer to those of the wire samples. The 50% pearlite reaction times were almost the same for ingot and bar samples. The times required to finish pearlite transformation in the bar samples were, in general, shorter than those for ingot material and about the same as for the wire samples.

There was distinct evidence of variations of pearlite transformation characteristics across the section of the bars. The incubation periods for the bar from the top of ingot 5 rose to a maximum in the columnar zone and then dropped steadily towards the bar axis, and the time to complete the pearlite transformation was, on average, higher for the equiaxed zone than for the columnar zone.

Bainite incubation periods and times for 50% bainite formation were not markedly different for ingot, bar, and wire material. Total transformation times were however, on average, less for bar than for ingot material, although, like the ingot samples, none of the bar samples transformed completely at 400° C.

Thus it was found that the transformation characteristics of the bar material were between those of the ingot and wire samples, and in this respect the hot-reduction process was clearly beneficial. Nevertheless, bar material was still far from uniform in its transformation response.

Consideration was next given to the incidence of chemical heterogeneity in the various ingot and bar samples, as this would influence the transformation behaviour.

Possible Effects of Macrosegregation

It was concluded by the Hardenability Sub-Committee[1] that longitudinal and transverse variations of hardenability could not, in general, be accounted for by macrosegregation of carbon or alloying elements. It was, nevertheless, considered desirable to assess the extent to which macrosegregation could account for the variations in transformation characteristics observed in the material used in this investigation. Accordingly, slices from the tops and bottoms of ingots 5 and 12 were analysed at the positions marked '*S*' in Fig. 4 for ingot 5; the macrostructures of the two ingots were similar. The carbon, sulphur, and phosphorus values were determined chemically, but the amounts of the other elements present were determined spectrographically. The results obtained are summarized in Tables IX and X.

Phosphorus was the only element which appeared to be segregated appreciably on a macroscale, the

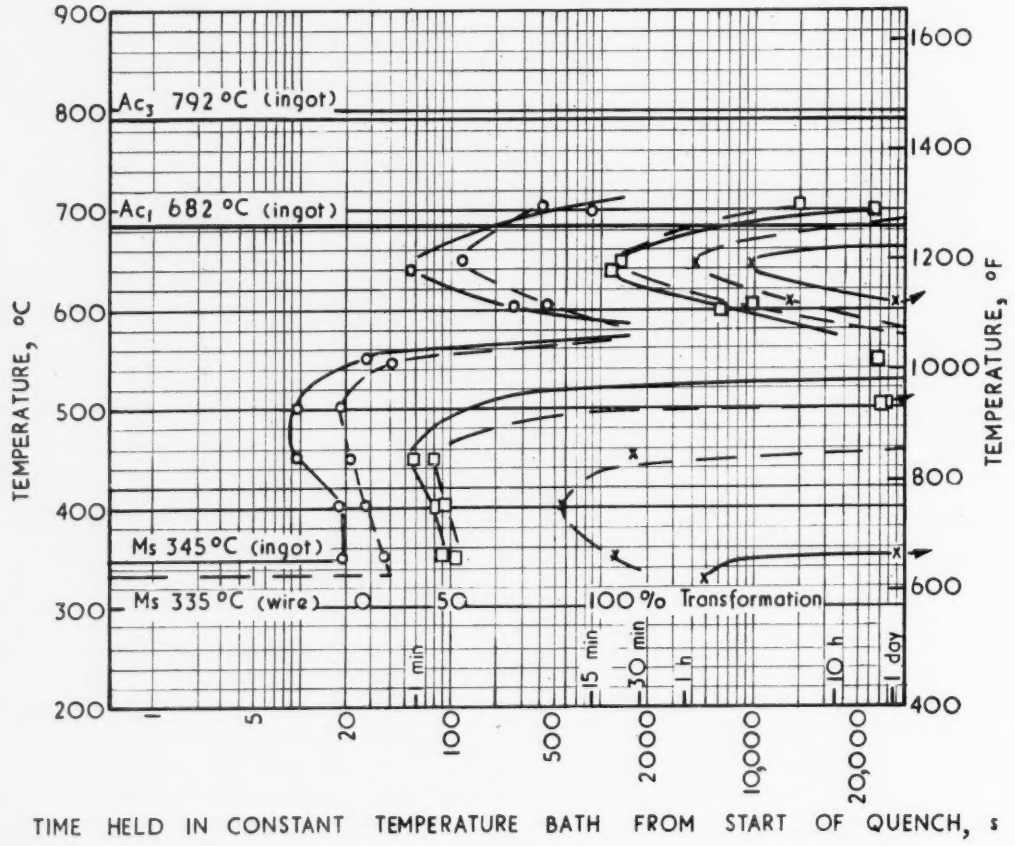


Fig. 5—Isothermal transformation diagram for the equiaxed zone of the bottom of ingot (full line) and for 9-gauge wire (broken line) from the same ingot position

phosphorus content in general decreasing towards the axis of the ingot. The latter effect is shown by the values given in Table X. Peak phosphorus contents were observed in the outer regions of the equiaxed zone at the top of ingot 5 (0·036% phosphorus) and in the columnar zone at the bottom of ingot 12 (0·042% phosphorus). It is significant that the positions of these peaks correspond approximately with those of the peak pearlitic incubation periods. Other investigators[7, 8] have demonstrated that phosphorus increases hardenability in steels, i.e. retards the early stages of transformation to non-martensitic products, but in general the effect on hardenability is small when the phosphorus content is below 0·15%. On this evidence small changes in phosphorus content in the cross-sections of the two ingots would not be expected to produce the peak transformation characteristics of the magnitude observed. On the other hand, the chemical test positions do not correspond exactly with those of the transformed samples, and the effect of macrosegregation of phosphorus was studied more closely by determining the content of this element in the series of dilatometer samples from positions *A*, *B*, *C*, and *D* in the top of ingot 5. The phosphorus analyses were 0·036%, 0·039%, 0·043%, and 0·043% respectively. These values do not account for the peak pearlitic incubation periods and it was concluded that the transformation characteristics of the ingot samples could not be explained on the basis of phosphorus macrosegregation.

Effects of Microsegregation

At this stage of the investigation a theory was formulated linking variation of transformation characteristics with microsegregation of alloying elements and possibly also of carbon. A steel with a dendritic structure contains, in the as-cast condition, dendrite 'spines' which have lower carbon and alloy contents than the average analysis, and interdendritic zones which have higher carbon and alloy contents than the

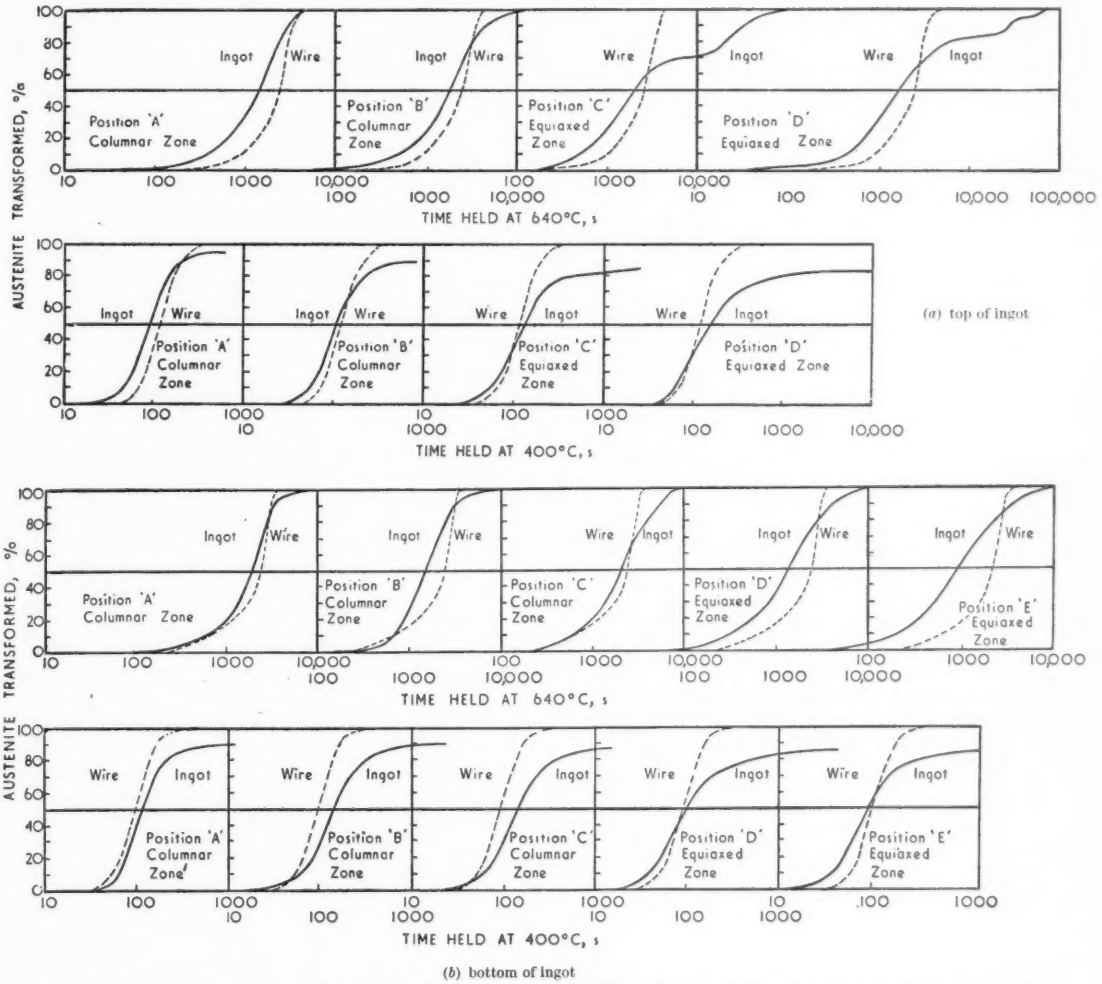


Fig. 6—Dilatation curves of samples from selected positions in the columnar and equiaxed zones of macrostructure of ingot (5 see also Fig. 4)

Table VI

THE PEARLITE AND BAINITE TRANSFORMATION CHARACTERISTICS OF INGOT AND WIRE SAMPLES FROM THE TOP AND BOTTOM OF INGOT 12

Position in ingot	Transformation temperature, °C	Incubation period, s	Time to 50% transformation, min	Time to end of transformation, h	Extent of transformation, %	Hardness, D.P.N.
Top						
Columnar zone, Position A	640	100	50	2·20	100	253
„ „ „ B	„	100	23	1·70	100	230
Equiaxed zone, „ C	„	150	43	1·70	100	254
„ „ „ D	„	60	22	5·50	100	250
Sample machined from wire	„	100	57	1·70	100	230
Columnar zone, Position A	400	20	1·8	0·11	90–95	361
„ „ „ B	„	30	1·9	0·55	90–95	363
Equiaxed zone, „ C	„	20	1·9	0·20	85–90	354
„ „ „ D	„	15	2·1	0·28	85	380
Sample machined from wire	„	33	1·8	0·17	100	387
Bottom						
Columnar zone, Position A	640	30	17	1·10	100	226
„ „ „ B	„	60	43	3·30	100	259
„ „ „ C	„	100	19	2·80	100	229
Equiaxed zone, „ D	„	30	41	5·50	100	246
„ „ „ E	„	40	46	2·80	100	230
Sample machined from wire	„	90	72	2·80	100	247
Columnar zone, Position A	400	20	1·7	0·42	95	364
„ „ „ B	„	15	1·6	0·55	95	373
„ „ „ C	„	25	1·7	1·40	90	389
Equiaxed zone, „ D	„	15	2·0	0·28	85	362
„ „ „ E	„	10	1·5	0·55	82	361
Sample machined from wire	„	33	2·0	0·17	100	377

Table VII

THE PEARLITE AND BAINITE TRANSFORMATION CHARACTERISTICS OF INGOT, 2-in. SQUARE BAR, AND WIRE SAMPLES FROM THE TOP OF INGOT 5

Position in cross-section of ingot and bar	Transformation temperature, °C	Incubation period, s		Time to 50% transformation, min		Time to end of transformation, h		Extent of transformation, %		Hardness, D.P.N.	
		ingot	bar	ingot	bar	ingot	bar	ingot	bar	ingot	bar
Columnar zone	640										
Outside		32	100	23	30	1·40	1·17	100	100	208	207
Inside		60	350	30	43	4·20	1·25	100	100	210	223
Equiaxed zone											
Outside		120	150	32	32	22·06	1·50	100	100	208	223
Mid-way		30	100	27	26	19·50	2·80	100	100	213	225
Centre		...	20	...	16	...	1·40	...	100	...	207
Sample machined from wire	640	150		42		1·40		100		207	
Columnar zone	400										
Outside		15	20	1·4	1·8	0·17	0·11	95	85	351	339
Inside		15	30	1·6	2·6	0·22	0·22	90	75	351	347
Equiaxed zone											
Outside		22	30	2·0	2·4	1·40	0·19	85	80	358	345
Mid-way		30	35	2·3	2·3	5·50	0·19	85	80	345	345
Centre		...	20	...	1·8	...	0·14	...	80	...	340
Sample machined from wire	400	34		1·8		0·22		100		363	

Table VIII

THE PEARLITE AND BAINITE TRANSFORMATION CHARACTERISTICS OF INGOT, 2-in. SQUARE BAR, AND WIRE SAMPLES FROM THE BOTTOM OF INGOT 5

Position in cross-section of ingot and bar	Transformation temperature, °C	Incubation period, s		Time to 50% transformation, min		Time to end of transformation, h		Extent of transformation, %		Hardness, D.P.N.	
		ingot	bar	ingot	bar	ingot	bar	ingot	bar	ingot	bar
Columnar zone	640										
Outside		30	240	29	25	2·20	0·7	100	100	217	215
Mid-way		150	200	24	28	2·20	0·8	100	100	224	210
Inside		180	135	33	20	2·50	1·0	100	100	227	219
Equiaxed zone											
Mid-way		60	120	22	20	3·60	1·0	100	100	208	217
Centre		27	90	16	17	3·30	1·1	100	100	203	220
Sample machined from wire	640	210		38		1·40		100		213	
Columnar zone	400										
Outside		30	25	1·7	1·8	0·25	0·17	90	85	360	353
Mid-way		20	40	2·2	2·3	0·55	0·13	90	80	370	354
Inside		30	30	2·2	2·3	0·55	0·14	85	85	362	356
Equiaxed zone											
Mid-way		20	22	1·7	1·6	1·40	0·13	85	85	365	351
Centre		10	20	1·3	1·7	0·55	0·14	85	90	359	348
Sample machined from wire	400	30		1·6		0·13		100		361	

average. It is appreciated that there is no clear-cut line of demarcation between spines and infilling but rather a continuous gradation from the one to the other, but in the subsequent discussion it will be convenient to consider only the zones of extreme composition and these will be referred to as ' dendritic spines ' and ' interdendritic zones.'

Table IX

SPECTROGRAPHIC AND CHEMICAL ANALYSES DETERMINED IN THE CROSS-SECTION OF INGOTS 5 AND 12

Element	Range of chemical analyses (wt-%) at:	
	Top of ingot 12	Bottom of ingot 12
Carbon	0·37 –0·39	0·36 –0·39
Silicon	0·22 –0·24	0·23 –0·25
Manganese	0·59 –0·64	0·60 –0·66
Nickel	1·28 –1·34	1·29 –1·35
Chromium	0·96 –1·00	0·96 –1·00
Molybdenum	0·23 –0·26	0·21 –0·26
Sulphur	0·021–0·025	Not determined
Phosphorus	0·028–0·040	0·029–0·042
	Top of ingot 5	Bottom of ingot 5
Carbon	0·37 –0·39	0·36 –0·37
Silicon	0·17 –0·20	0·17 –0·20
Manganese	0·56 –0·64	0·60 –0·64
Nickel	1·29 –1·38	1·30 –1·40
Chromium	0·99 –1·04	0·97 –1·04
Molybdenum	0·23 –0·28	0·23 –0·29
Sulphur	0·018–0·023	0·017–0·022
Phosphorus	0·024–0·036	0·028–0·030

In a material having a dendritic structure, or the residues of a dendritic structure remaining after hot-working, the dendritic spines will, because of their lower alloy and carbon content, transform first, and consequently these zones define the incubation period of the aggregate at any transformation temperature. The interdendritic zones start transforming later and finish transforming later than the dendritic spines, and the most highly alloyed of these zones determines the time required by the aggregate to transform completely at any temperature.

The transverse variations of hardenability observed in ingots and wrought material can be accounted for by postulating that they are due to differences in transformation characteristics caused by varying degrees of microsegregation within the metal. The more severely a zone is microsegregated, the more readily will it start to transform to pearlite or bainite and consequently the lower will be its hardenability as assessed by an end-quench hardenability curve. On the other hand, the more severe the microsegregation the longer a sample will require to transform completely to pearlite or bainite and, indeed, microsegregation may prevent complete transformation occurring at certain temperatures, particularly in the bainite range. This, however, will be reflected only in the lower part of the end-quench hardenability curve and will not appear as an increase in hardenability.

The degree of microsegregation of an unforged ingot would be expected to vary across its section, and the pattern of this variation is considered to account for

Table X

THE VARIATIONS IN PHOSPHORUS CONTENT IN THE CROSS-SECTIONS OF INGOTS 5 AND 12

Ingot		Phosphorus content, wt-%	
		Columnar zone*	Equiaxed zone*
No. 5	Top	0·031(+ S_1), 0·030(+ S_3)	0·036(+ S_2), 0·036(+ S_4), 0·029(+ S_{5+}) 0·027(+ S_6), 0·024 (centre)
	Bottom	0·028(+ S_1), 0·030(+ S_3), (0·028(+ S_4)	0·030(+ S_5), 0·028(+ S_7), 0·030(+ S_7), 0·028(centre)
No. 12	Top	0·040(+ S_1), 0·036(+ S_3)	0·036 (+ S_4), 0·034(+ S_6), 0·028 (centre)
	Bottom	0·032(+ S_1), 0·036(+ S_3), 0·042(+ S_4)	0·034(+ S_5), 0·036(+ S_7), 0·029 (centre)

* Code letters in brackets refer to analysis positions in Fig. 4.

Table XI

CHEMICAL COMPOSITIONS OF DENDRITIC AND INTERDENDRITIC REGIONS OF INGOT 5. MICROSTRUCTURE, AS DETERMINED BY THE CASTAING METHOD

Position in ingot	Element	Average Spectrographic analysis, wt-%	Castaing Analysis, wt-%*	
			Dendrite (dark-etching)	Infilling (light-etching)
Columnar zone	Nickel	1·32	1·12–1·30	1·4 –1·6
	Chromium	0·99	0·78–0·85	1·08–1·17
	Manganese	0·61	0·58–0·61	0·58–0·75
Equiaxed zone	Nickel	1·29	1·2 –1·45	1·45–2·3
	Chromium	0·97	0·72–0·77	1·05–1·12
	Manganese	0·61	0·6 –0·7	0·38–0·8

* Ranges quoted are the maximum and minimum values of ten tests.

the observed variations of hardenability and transformation characteristics. By promoting diffusion, forging and hot-rolling will modify the pattern developed during solidification and ultimately hot-working would be expected to destroy the pattern almost completely. The evidence so far presented in this paper would suggest that the material near the ingot axis is more severely microsegregated than that near the surface, and that hot-working to 2-in. square bar reduces slightly but significantly the extent of the microsegregation.

The second part of this paper is devoted to providing further evidence to substantiate the role played by microsegregation in establishing hardenability variations.

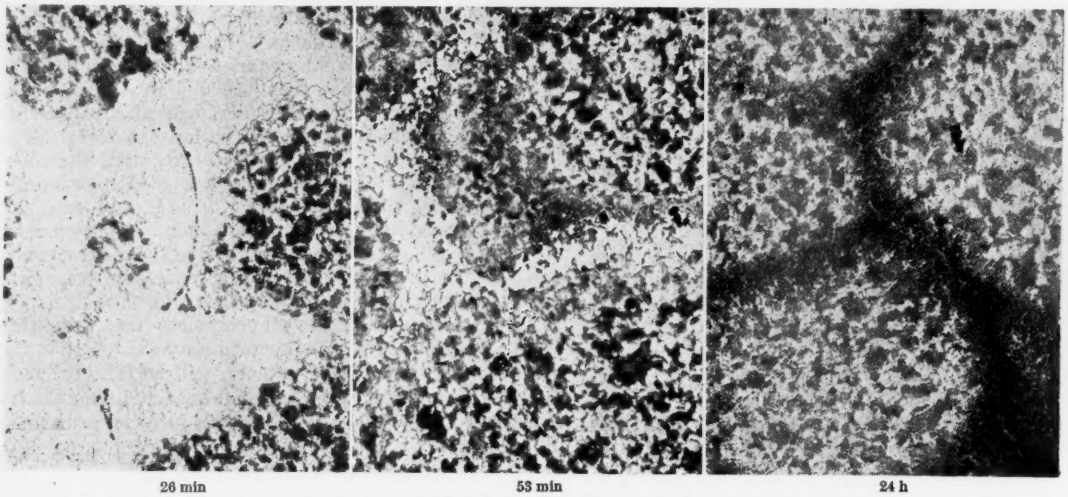
Part II—A Study of Microsegregation and of the Effects of Diffusion Treatments on the Variations in Transformation Characteristics in Ingot and Bar

Microstructural Evidence of Microsegregation

To demonstrate the manner in which microsegregation controls the progress of transformation, small samples were taken from various positions in the unforged slices from ingot 5. These were austenitized and then allowed to transform at selected temperatures in the pearlite and bainite range, the progress of transformation being followed by the microscopic method. This study clearly confirmed that transformation starts in the dendritic spines and progresses towards the interdendritic regions. Typical photomicrographs illustrating this for pearlite and bainite formation are reproduced in Figs. 7 and 8.

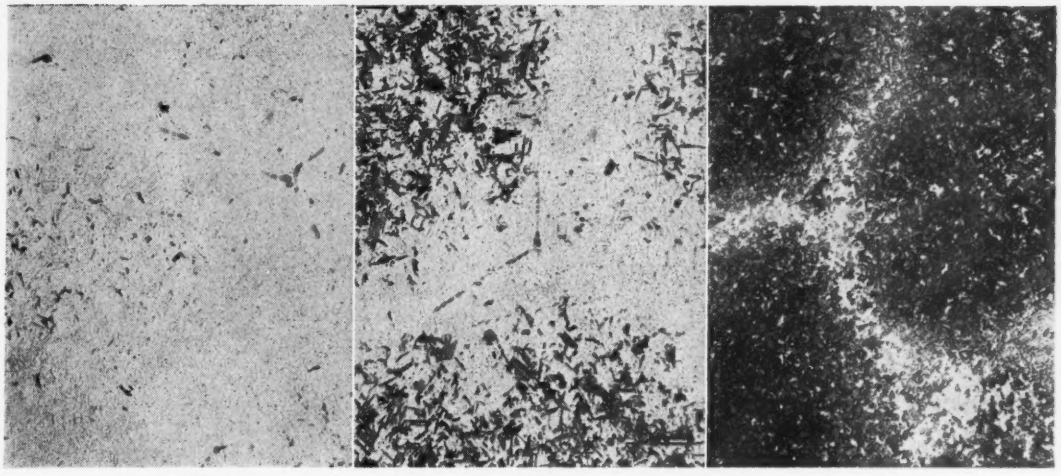
The formation of martensite in dendritic structures is illustrated by Fig. 9. In one particular sample from the equiaxed zone at the bottom of ingot 5 it was noted that martensite started to form in the dendritic spines at 345° C, but did not start to form in the interdendritic zones until 275° C. This difference of 70° C between the M_s temperature of the two zones could be accounted for by a carbon content difference of about 0·2% or a total alloy content difference of about 3%.

There was clear evidence that the intensity of



26 min 53 min 24 h

Fig. 7—Progress of transformation at 650° C in unforged material from the equiaxed zone at the bottom of ingot 5 × 150

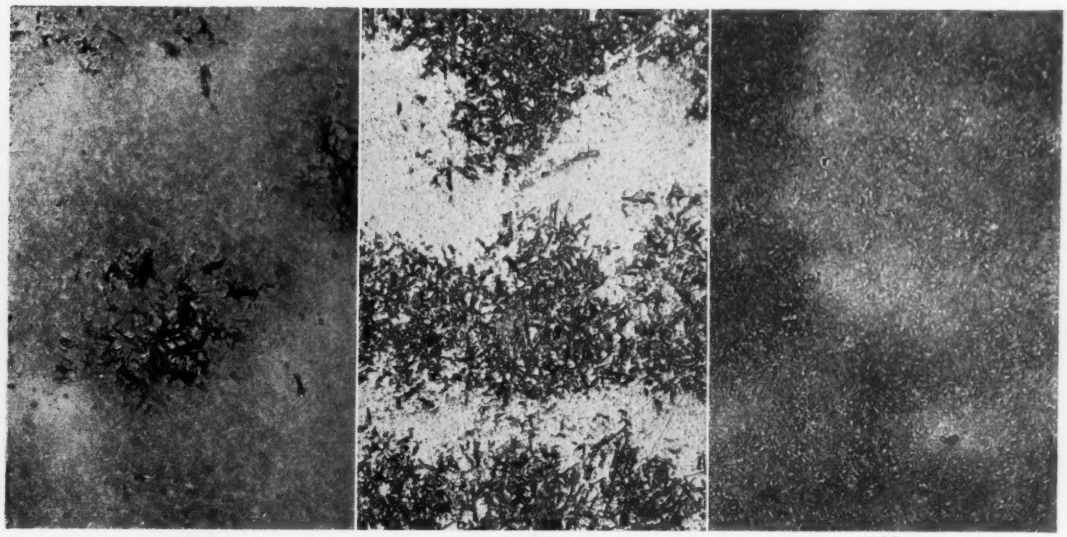


20 s 40 s 24 h

Fig. 8—Progress of transformation at 400° C in unforged material from the equiaxed zone at the bottom of ingot 5 × 150

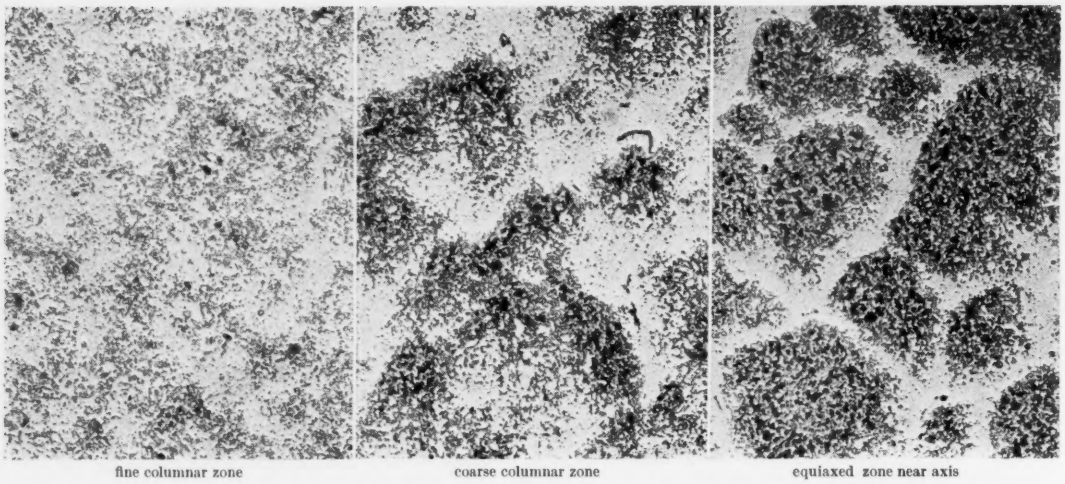
microsegregation increased towards the axis of the ingot. This is illustrated by the three fields of microstructure shown in Fig. 10. This transverse variation in degree of microsegregation was still apparent in the 2-in. square bar, as illustrated by the microstructures shown in Fig. 11, and from these and other fields of microstructure it was evident that the intensity of the microsegregation had been reduced by hot-working, but the effect was confined mainly to the outer portions of the bar.

The zones of pronounced microsegregation were outlined in the cross-sections of the bars as patterns on partly transformed samples such as those reproduced in Fig. 12. As these patterns demonstrate, the markedly segregated zones were more extensive in the bar from the bottom of the ingot than in that from the top. Thus a tapered microsegregated zone can be visualized occupying almost the whole of the equiaxed zone at the base, but only the axial zone at the top on the ingot. These patterns provide definite evidence of a longitudinal variation in the distribution of the lower hardenability material. The remnants of these patterns in 9-gauge wire samples have already been illustrated (Fig. 2). The longitudinal variation of the extent of the low hardenability zone was also revealed by hardness measurements on partly transformed ingot samples. These tests showed that the limit of the low hardenability zone did not coincide with the boundary between the columnar and equiaxed crystals, except at the bottom of the ingot,



320° C 305° C 100° C

Fig. 9—Progress of the martensite transformation in unforged material from the coarse columnar zone at the bottom of ingot 5 × 150

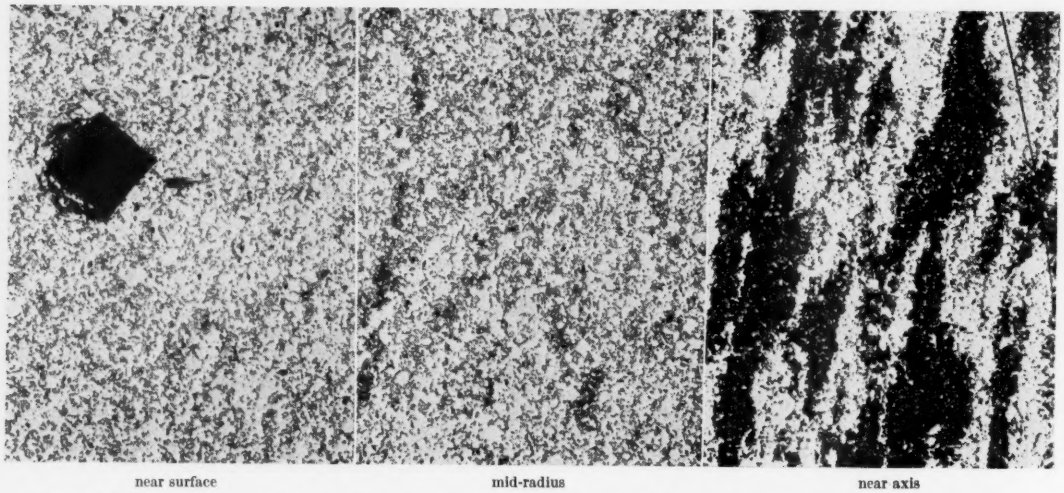


fine columnar zone | coarse columnar zone | equiaxed zone near axis

Fig. 10—Effect of increasing intensity of microsegregation towards ingot axis on extent of transformation after 1000 s at 640° C. Material from bottom of ingot 5 × 75

and that the area of the zone decreased towards the top of the ingot. This is in accordance with earlier work on ingot material by Allsop and Steven.[4] Full-length sulphur and macroprints of the particular B.S. En 24 steel ingots used for this work were not available, but Mr. H. Allsop kindly provided prints of a complete longitudinal section of an ingot of B.S. En 25 steel of the same size and produced under similar conditions of steelmaking. The macroprint reproduced in Fig. 13 shows a tapered zone of modified ingot structure, the boundaries of which correspond closely to those of the tapered zone of low hardenability shown to exist in ingot 5. Clearly an investigation is required of the conditions of solidification and movement of liquid steel in the mould which lead to the formation of this particular zone, which on the basis of the evidence of this paper is heavily segregated on a microscale.

Microscopical evidence of the nature of the microsegregation was obtained by studying the structures of samples of unforged ingot material heated at 700° C. The microstructure of a sample heated at this temperature for 1½ h and then quenched to room temperature (Fig. 14) showed that although the dendritic material had transformed at 700° C to austenite the interdendritic material had not. On the other hand, the microstructures of samples which had been fully austenitized at a higher temperature and then held at 700° C for 24 h before quenching to room temperature (Fig. 15) showed that the interdendritic material transformed at 700° C, but not so the dendritic material. These results suggest that the microsegregation is such that the interdendritic material has higher A_1 and A_3 temperatures than the dendritic material. This suggests microsegregation of phosphorus, silicon, or molybdenum; the effect of phosphorus in particular



near surface | mid-radius | near axis

Fig. 11—Effect of increasing intensity of microsegregation towards bar axis on progress of transformation after 1500 s at 640° C. 2-in. square bar material from top of ingot 5 × 75

on critical temperatures would be marked. The microsegregation of phosphorus has been studied by other investigators working on plain carbon-steel ingots, but evidence relevant to the present investigation has been obtained by a French investigator[9] who, by using a radioactive isotope, has shown that phosphorus microsegregates in nickel–chromium–molybdenum steel ingots in the same way as alloying elements, i.e. concentrating in the interdendritic regions. The same author also demonstrated that a homogeneous distribution of phosphorus could be established by annealing for 70 h at 1200° C.

The degree of microsegregation of material from a position of peak hardenability is compared with that of adjacent material of lower hardenability in Fig. 16. Both samples were partly isothermally transformed under similar conditions and their microstructures suggest that the intensity of microsegregation in the zone of peak hardenability is less than that of the adjacent material. Nevertheless, the authors are of the opinion that the occurrence of the zone of peak hardenability is not due wholly to the effects of microsegregation. The peak pearlitic incubation period of the ingot material is almost equal to the incubation period of the corresponding wire sample; if, therefore, the explanation is to be based wholly on the effects of microsegregation, it would follow that the ingot must contain a zone comparable in homogeneity to that of 9-gauge wire, forged, rolled, and drawn from the same

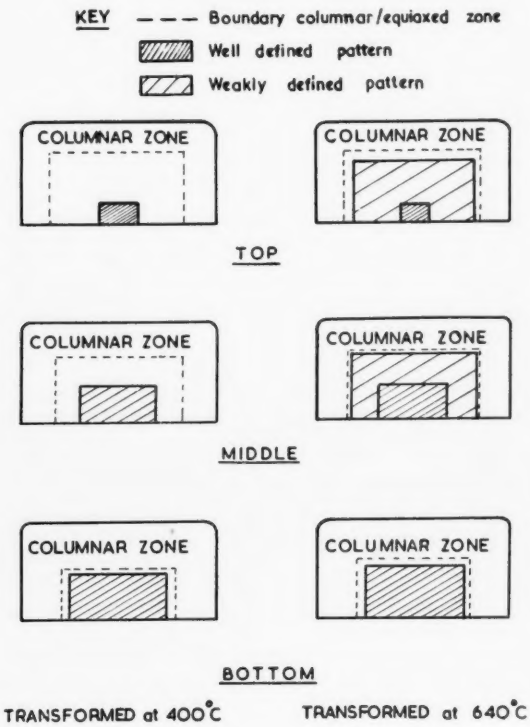
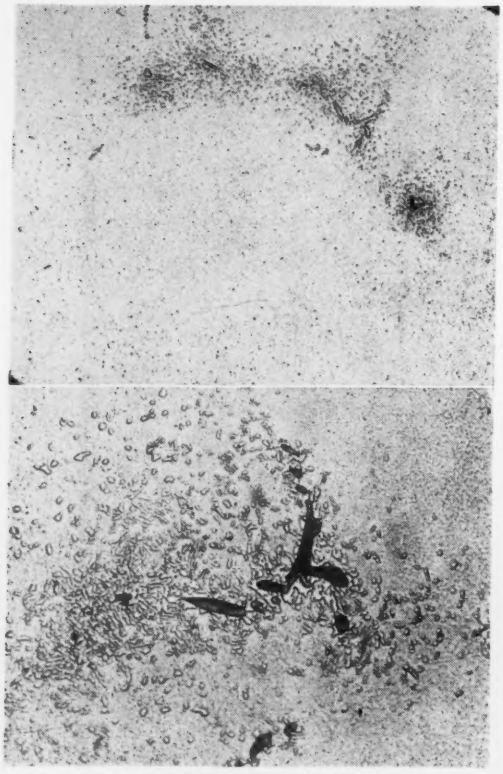


Fig. 12—Hardenability patterns in transverse sections of 2-in. square bar forged and rolled from the top, middle, and bottom portions of ingot 5

Fig. 13—Macrostructure of a B.S. En 25 steel ingot × ⅛ approx

(*a*) equiaxed zone × 150



(*b*) equiaxed zone × 500

Fig. 14—Progress of transformation to austenite after 1½ h at 700° C. Interdendritic regions indicated by non-metallic inclusions (bottom of ingot 5)

ingot. This is unlikely and it is suggested that the ingot material in the vicinity of a zone of peak hardenability is enriched by macrosegregation of an element which markedly increases hardenability, i.e. delays the early stages of transformation, and locally overrides the influence of microsegregation. As noted previously, it was thought that phosphorus might be the element responsible, but the evidence obtained was considered inadequate to establish a relationship.

Micro-analysis of Segregated Zones

It was appreciated at this stage that all the observations on microsegregation had been of an indirect nature, and the identity of some of the segregating elements had only been established by deduction from their effects on the microstructure and M_s temperature of the various ingot samples.

An attempt was made, therefore, to determine which of the common alloying elements segregated on a micro scale. Microradiographic tests demonstrated microsegregation of chromium and possibly of nickel and molybdenum in ingot material. The evidence obtained of the extent to which microsegregation varied across samples was disappointing, however, although the method did confirm the improvement effected by the diffusion-anneal treatment described later.

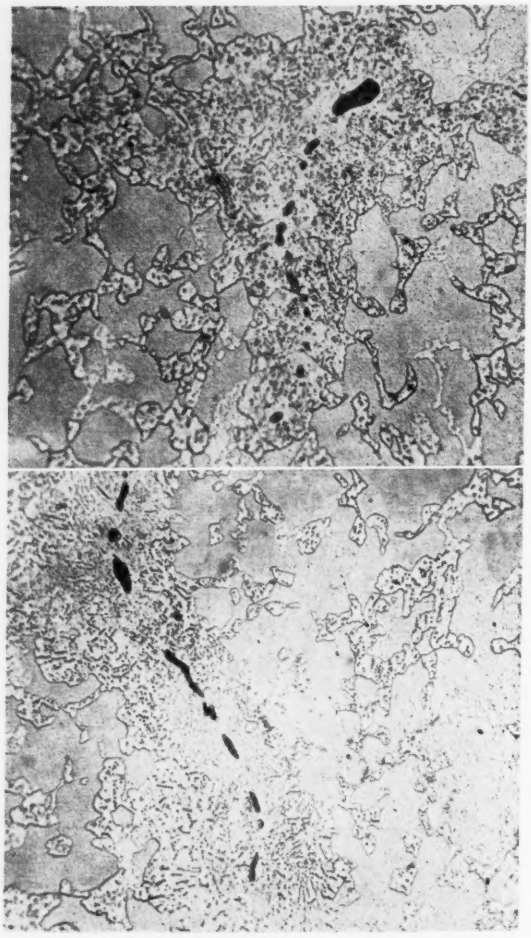
More detailed evidence was obtained for the authors by R. Castaing, using the micro-analysis method which has been described in detail elsewhere.[10, 11] Castaing assessed the nickel, chromium, and manganese contents of the dendritic spines and the interdendritic zones of unforged material from ingot 5, and his results are presented in Table XI.

These results confirm that the interdendritic regions are richer in nickel, chromium, and manganese. They also confirm that the nickel and manganese are segregated to a greater degree in the equiaxed zone than in the columnar zone of the ingot, but these limited tests provided no evidence to suggest that chromium is also more severely segregated in this part of the ingot.

The Effect of Homogenizing Treatments

If, as has been postulated, transverse variations of hardenability and transformation characteristics are

(*a*) columnar zone



(*b*) equiaxed zone

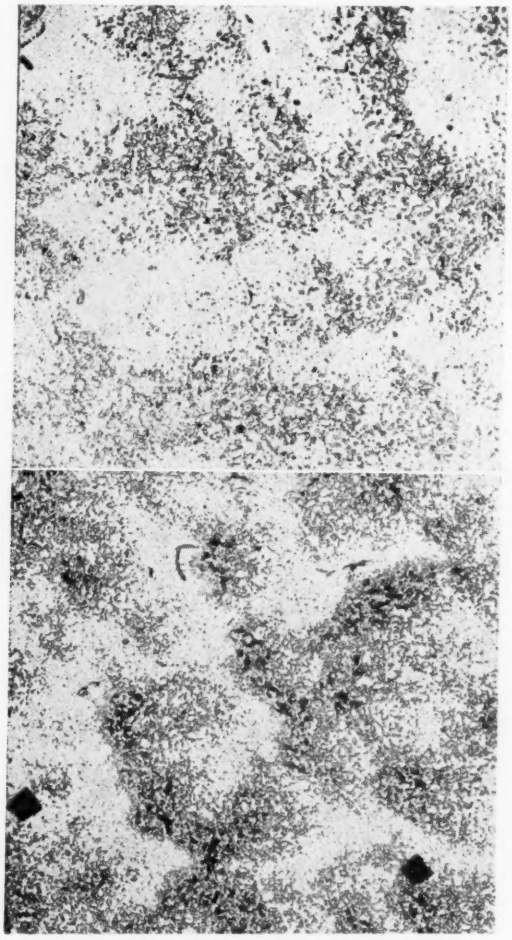
Fig. 15—Progress of transformation to pearlite after 24 h at 700° C. Interdendritic regions indicated by non-metallic inclusions (top of ingot 5) × 500

due to varying degrees of microsegregation, then it should be possible to reduce the magnitude of the variations by applying homogenizing treatments.

Samples of unforged ingot material and of 2-in. square bar material were treated by heating for 7 days *in vacuo* at 1200° C. As illustrated by Fig. 17, which shows the structures of ingot samples partly transformed to pearlite, bainite, and martensite, the treatment effectively reduced the extent of microsegregation. The persistence of some microsegregation is demonstrated, however, by the reaction curves of Fig. 18 which show that although the diffusion-annealed material started to transform later than the unannealed material and at the same rate as the corresponding wire sample, it transformed more sluggishly than the latter during the later stages of transformation.

More striking evidence of the effectiveness of the diffusion-anneal is provided by hardness surveys made on thin slices from the 2-in. square bar which had been subjected to the homogenizing treatment described above, re-austenitized, and then quenched after being allowed to transform to various degrees. The curves obtained are presented in Fig. 19 and compared with those for the unhomogenized material. The comparison shows clearly that the transformation characteristics across the bar are much more uniform than they were before the application of the homogenizing treatment. The homogenizing influence of the diffusion-anneal was also confirmed by the microstructures of the partly transformed material, which were free from banding, and by the absence of hardenability patterns.

(*a*) structure in zone of peak hardenability



(*b*) structure in zone of low hardenability, adjacent to that in (*a*)

Fig. 16—Variation in intensity of microsegregation at positions of peak and low pearlitic hardenability. Ingot samples transformed at 640° C for 1000 s

× 75

SUMMARY AND DISCUSSION

The principal features revealed by the investigation can be conveniently summarized as follows:

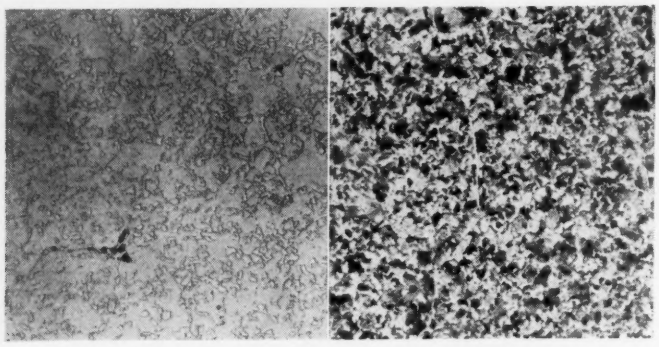
(1) The transformation characteristics of 9-gauge wires, derived from the top, middle, and bottom of 1¼-ton ingots of B.S. En 24 steel, were not markedly different, the greatest difference between transformation times being of the order × 2. The transformation characteristics of wires derived from different ingots from the same cast of steel did not differ by greater amounts.

(2) Marked differences were apparent between the transformation characteristics of these wires and of unforged samples from the original ingots. For example, the incubation periods for the ingot material, particularly those for the pearlite range, were shorter than those for the wires by a factor as low as × ½. The most marked differences, however, were the very much longer total reaction times, in one instance twenty-five-fold, of the ingot material in both the pearlite and bainite ranges of transformation. The isothermal transformation characteristics of 2-in. square bar material more closely approached those of the wire samples but, in general, the bar material started to transform sooner and had longer total reaction times than the wire material.

(3) Transverse and longitudinal variations of transformation characteristics were apparent in both the ingot and bar. In general, the material near the axis started to transform earlier and took longer to transform completely than the material near the surface. The extent of this zone of low hardenability decreased from the bottom to the top of the ingot and corresponded with a zone apparent in the ingot macrostructure. There was also some evidence of a narrow intermediate zone of high pearlitic hardenability in the ingot which started to transform later than the material near the axis or near the surface, with incubation periods almost equal to those of the wire samples.

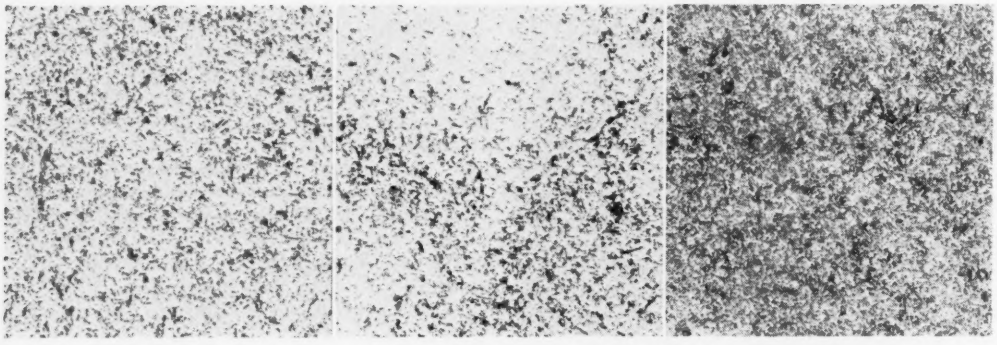
(4) The observed variations of transformation characteristics could not be accounted for by segregation of carbon and the major alloying elements on a macroscale, but evidence was obtained from unforged ingot material that nickel, chromium, manganese, and molybdenum all segrated on a microscale, and indications were also obtained of the possible microsegregation of silicon or phosphorus. Carbon diffuses so rapidly on a microscale that its influence on the

phenomena under study is considered to be of secondary importance. The intensity of microsegregation increased towards the axis of the ingot and bar, and a tapered zone of severe microsegregation was found to occupy almost the whole of the equiaxed zone at the bottom of the ingot, but only the axial zone at the top of the ingot. These features accounted for substantially all the longitudinal and transverse variations of hardenability and transformation characteristics observed, but the intermediate zone of peak hardenability has not been satisfactorily explained. It is suggested that this is due to the effects of an element



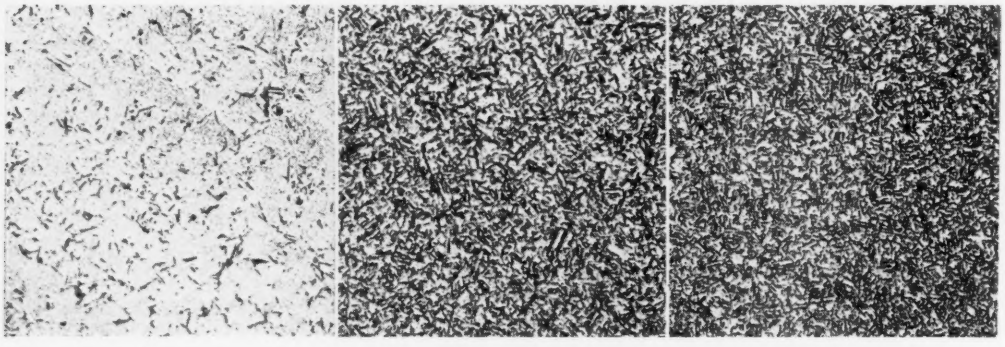
equiaxed zone, partial transformation — equiaxed zone, end of transformation

(*a*) transformation to ferrite and pearlite at 640° C



columnar zone, partial transformation — equiaxed zone, partial transformation — equiaxed zone, end of transformation

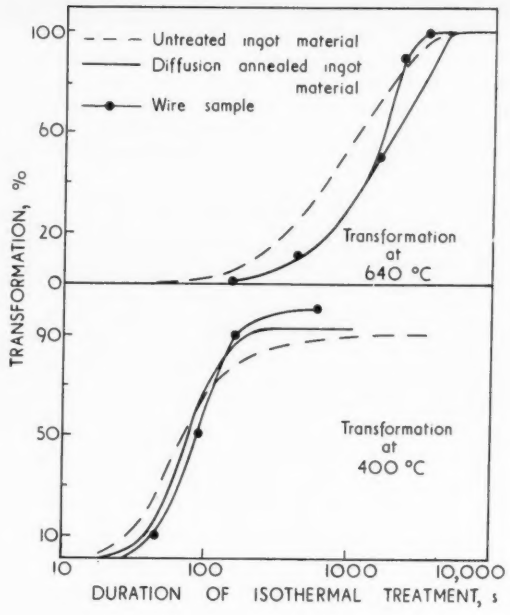
(*b*) transformation to bainite at 400° C



columnar zone, 305° C — columnar zone, 275° C — equiaxed zone, 275° C

(*c*) transformation to martensite

Fig. 17—Progress of transformation in diffusion-annealed ingot material × 75

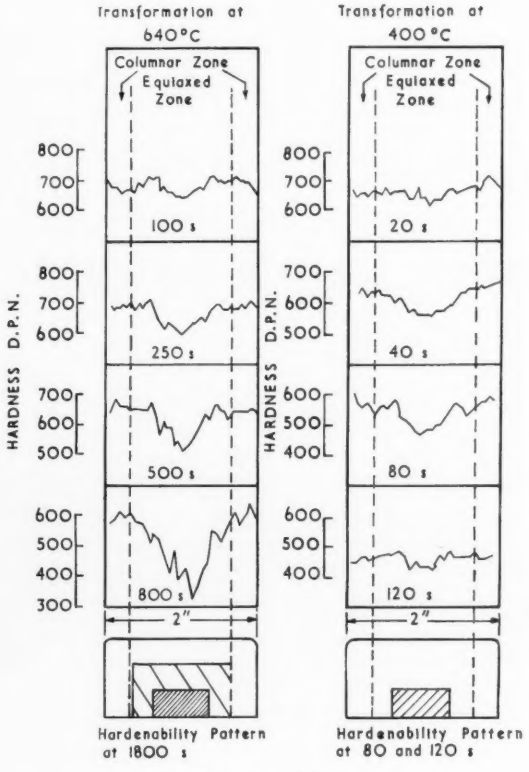


segregated on a macroscale, and in this connection the possible role of phosphorus deserves further study.

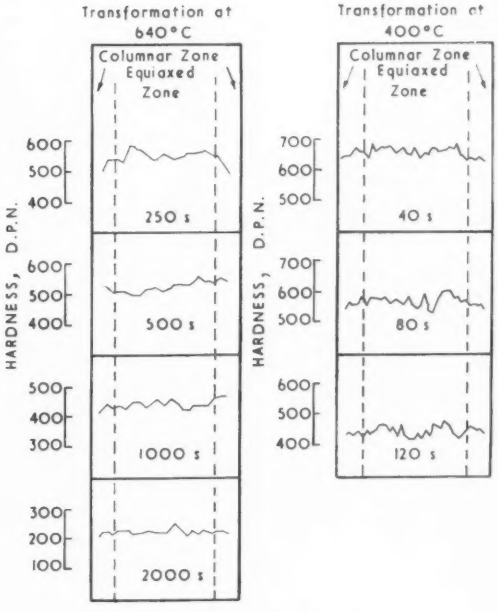
(5) The intensity of microsegration in both ingot and bar material was substantially reduced by annealing for a few days at 1200° C, and the variations in transformation characteristics largely disappeared. This response to the homogenizing treatment provided strong supporting evidence for the role of microsegregation.

The existence of a zone of low hardenability within normal commercial ingots has hitherto not been fully appreciated, but the present investigation has revealed a unique link between this zone and considerable microsegration of several elements. Any theory of the sequence of events occurring during the solidification of an ingot must include an explanation of the formation of this zone. It is the authors' opinion that in this connection the accumulation of detailed knowledge of the solidification of ingots is of considerable importance.

Fig. 18—Comparison of isothermal reaction curves for diffusion-annealed and unannealed ingot material from the equiaxed zone with those for 9-gauge wire



(*a*) not annealed



(*b*) diffusion-annealed at 1200° C

Fig. 19—Influence of homogenization on the form of the hardness traverse curves of partly transformed bar material

The hardenability variations within an ingot are clearly passed on to the billet and bar of the hot-worked steel, and, depending on the commercial importance of the problem, a study might be made of methods of controlling the hardenability variations in ingot material to obtain a more homogeneous wrought product. Such a study would start with a systematic survey of the effects of variables such as pouring temperature, pouring speed, ingot size, ingot shape, etc., but the nature of subsequent work would depend on the theory most favoured to explain the development of the zone of low hardenability during the solidification of an ingot. If, for example, it is considered that the zone is due to the formation of falling crystallites, then the possibility of modifying its extent by adding inoculants might be pursued.

Finally it is stressed that the commercial importance of variations of hardenability across the sections of bars of commercial steel has still to be established, with perhaps particular emphasis on the effects of the hardenability variations on mechanical properties, notably the tensile and impact properties. On the basis of the present investigation, material forged from (*a*) the top of an ingot, and (*b*) the bottom of an ingot, is appropriate for comparative studies.

CONCLUSIONS

It is concluded from the survey of the transformation characteristics of 14-in. B.S. En 24 steel ingots, and of 2-in. square bar and 9-gauge wires produced from them, that the longitudinal and transverse variations in hardenability that existed within the ingot and between the three sizes of material are due to variations in the intensity of microsegregation of the principal alloying elements Ni, Cr, Mn, and possibly of Mo and P.

Hot-working operations, such as forging and rolling, only slightly reduce the intensity of microsegregation, but prolonged diffusion-annealing treatment at high temperature produces almost complete chemical homogeneity and eliminates the hardenability variations.

Acknowledgment

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Proposal for a Self-lining Blast-furnace

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T. P. Brown, and

L. A. Leonard, B.Sc., A.R.I.C.

EVERY YEAR the British iron and steel industry consumes more than 50 million tons of ore, coke, and limestone. This vast stream of granular material has to flow through blast-furnaces to provide iron for both direct casting and processing to finished steel. Improved efficiency and increased production, which are so essential to the national economy, have been promoted in modern practice by the use of large rather than small furnaces, and by integrating them with steelmaking plants and rolling mills. These arrangements, however, put a heavy premium on long, trouble-free, blast-furnace campaigns.

SYNOPSIS

The blast-furnace has been considered as a pipe through which granular materials flow. Its behaviour has been examined by a theoretical approach, model work, and observation of blown-out furnaces. The mechanisms of wear, hanging, and scaffold formation have been outlined. This work has led to proposals for a self-lining furnace in which baffles trap material from the charge to act as a self-renewing refractory lining, and stack tuyeres are used to control hanging and scaffolds. 1405

A 16-mm sound film "*A Self-lining Blast-furnace*" is available on loan from B.I.S.R.A. This film was shown at the 24th Blast Furnace Conference in October, 1956.

Paper C/1/57 of the Chemistry Department of the British Iron and Steel Research Association, received on 11th March, 1957.

Dr. Archibald is Head of the Refractories and Slags Section of the B.I.S.R.A. Chemistry Department, and Mr. Brown and Mr. Leonard are members of the Section.

Essentially the blast-furnace is an almost cylindrical steel shell lined with refractory brickwork. Fireclay bricks are the most common lining material, but recently carbon blocks have been displacing them in the hearth and bosh (Fig. 1).

Sooner or later the refractory lining becomes unable to deal with the flow of raw materials, so that the furnace has to be shut down for relining. This means that every few years many weeks of valuable production are lost between campaigns. Shut-downs, which can sometimes be very premature, are caused mainly by severe changes in the furnace lines (Fig. 2). These changes are of two opposite kinds, the loss and gain of material (i.e. wear and growth), both of which can occur within the same lining. Eventually wear of the brickwork allows the shell to become dangerously hot, whilst growth of material coming from the furnace contents produces scars and obstructive scaffolds.

This paper describes research undertaken to overcome these disadvantages, and begins by outlining the nature of the charge, the refractory, and the mechanisms at work in the furnace.

Part I—BEHAVIOUR OF BRICK-LINED FURNACE

Definition of a Refractory

Defined as simply as possible, a refractory is a material which remains sufficiently *firm* to survive for a reasonable time under high-temperature service conditions. Only three types of material are suitable:

(1) **Massive rigid-elastic** material, which is solid, usually crystalline
(2) **Massive stiff-plastic** material, which is *partly solid and partly liquid*. (Highly viscous material which is all liquid may be considered to come under the same category)
(3) **Granular** material of either of these types, provided that it is under some compression and restraint to make it act as a stationary coherent mass.

Refractories Existing in the Blast-furnace

The contents of the blast-furnace shell, *refractory* and *charge*, can be divided roughly into two zones according to the physical state of the material (Fig. 3).

The upper, cooler zone is one of rigid solids, and the lower, hotter zone contains liquids. This classification, of course, does not refer to the *cooler* parts of the refractory near the shell, where rigid properties prevail from top to bottom. It should be noted that although the *brick wall* and the self-supporting *column of charge* are both refractory, they differ in that the former is massive and the latter is granular.

Movement of Materials in the Blast-furnace

The top of the column (i.e. the stockline) is maintained at an approximately constant height by regular charging. The blast pushes the gases upwards at about 11 ft/s against the resistance* offered by the channels through the porous burden. As pieces of solid are lost near the base, by conversion to gas or liquid, the force of gravity pulls the self-supporting column of burden downwards (at about 10 ft/h) against the resistance of the walls. All the fluids move towards the exits: the gases join the upward stream, and the liquids in the main trickle over the slower-moving solid granules, but also drain down the walls.

Liquid slag and iron, which accumulate in the hearth, are periodically drawn off from between the lumps of burden at the foot of the column *without affecting the regular flow of solids*, liquids, or gases above the hearth. The gases emerging from the stockline are taken away through the offtakes at the top.

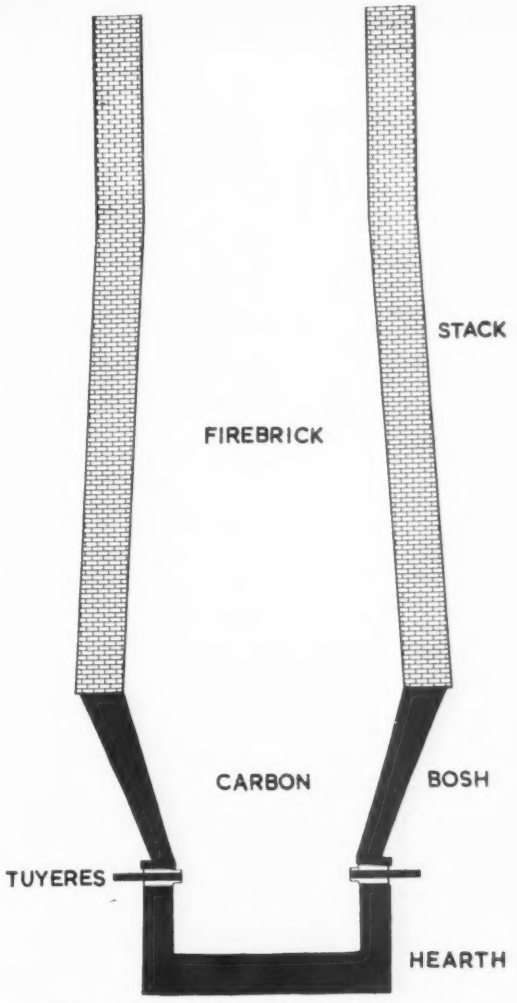


Fig. 1—Blast-furnace, showing brickwork

Forces Acting on the Refractory Walls

The mechanical forces acting on the refractory walls are due partly to the movements of solids, liquids, and gases. They are:

(1) Compressive forces, due to the weight of the charge, the weight of the bricks, and the pressure of the gases

* The gas velocity quoted is the mean velocity of the gas in the blast-furnace. It is calculated from the volume of gas passing unit cross-sectional area of the furnace at its average diameter and at an average temperature estimated to be 1000° C. When allowance is made for the fact that the gas has to travel through the voids in the burden material, comprising 25–50% of the volume, its velocity will lie between 44 and 22 ft/s, i.e. a maximum value of about 30 m.p.h.

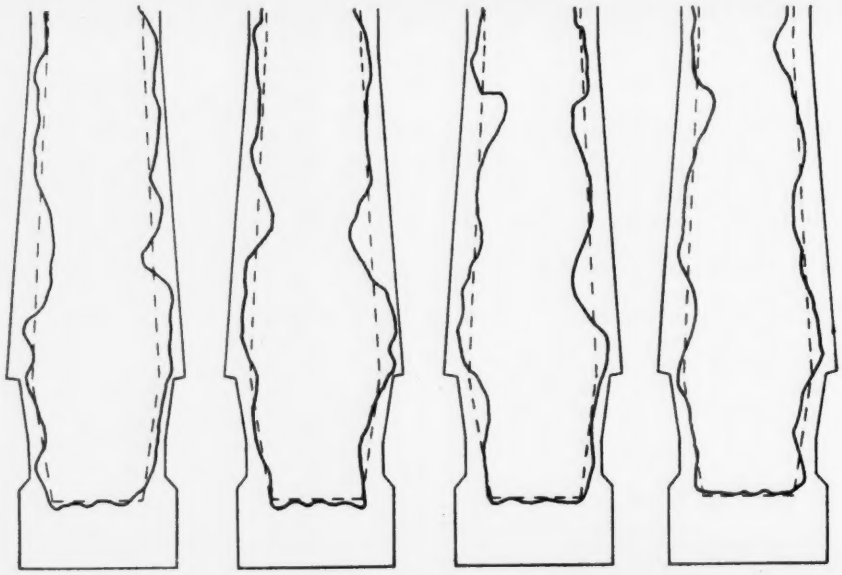


Fig. 2—Typical lines of blown-out furnaces

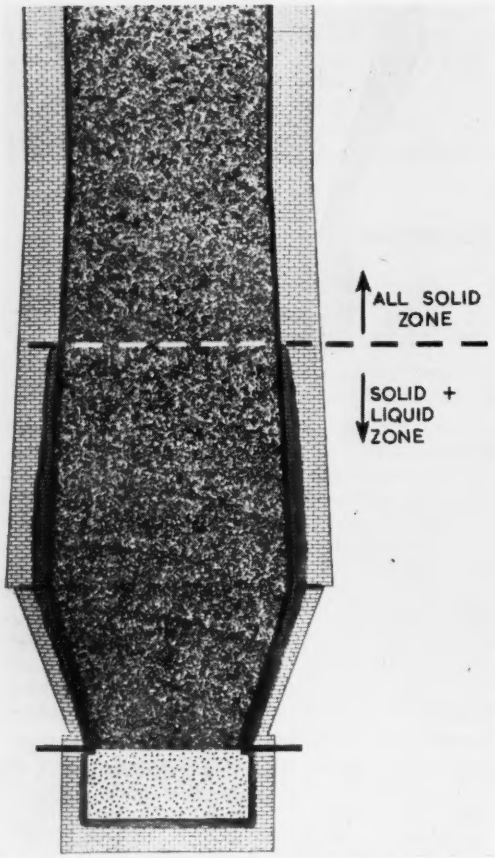
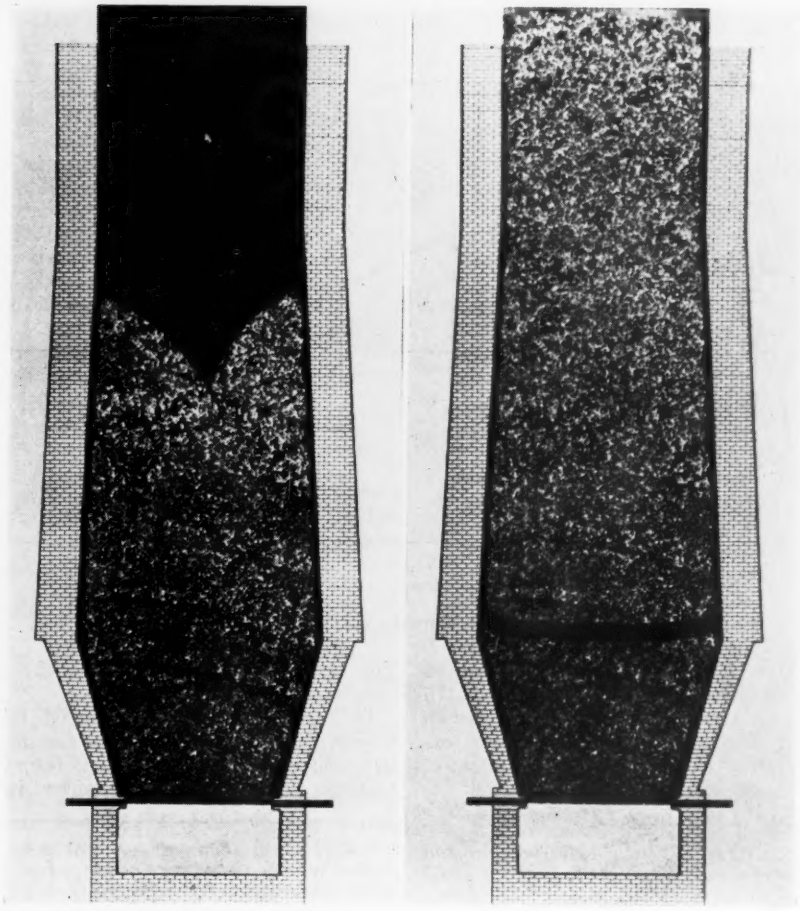


Fig. 3—Distribution of solid and liquid phases in furnace

Fig. 4—Flow model blast-furnace



(*a*) Stockline allowed to descend (*b*) Stockline maintained

Fig. 5—Flow of granules down furnace

(2) Abrasive shear forces caused by the movement of the gases upwards (about 0·20 lb/ft²/s) and the burden downwards (about 0·15 lb/ft²/s).

The downward movement of the solid charge and the upward flow of the gases give rise to the principal wearing forces. The extent of wear under these conditions depends on the abrasive resistance of the refractory in service.

Abrasion tests carried out in the laboratory on *cold new* bricks provide little indication of their potential performance, because in vital areas in the stack and bosh the properties of the refractory are seriously impaired by slag attack and disintegration. Elsewhere in the furnace, moderate wear or even considerable growth are evident, all in face of these *scouring actions*.

The amount of abrasive wear occurring at different positions in the furnace is diminished by the *presence of lubricating liquids*. The effectiveness of this depends on the quantity and the nature of the liquids concerned. High in the 'dry' zones of the furnace severe abrasive wear, even of sound bricks, is commonly encountered.

Flow Model of Blast-furnace

A slice model was constructed in order to study these phenomena (Fig. 4). It was a glass-fronted box 24 in. × 15 in. × 9 in. which was charged at the top with granules chosen to represent the size of the materials in the furnace. The inside contour was adaptable, so that it could represent a furnace of any desired shape. To produce a downward flow of the burden, provision was made for discharging granules by means of an inverted **V** gate at the bottom of the hopper-like model. A band of black granules was used to make the flow pattern more readily visible.

When the stockline in the model was allowed to fall, it did so in **V**-formation (Fig. 5*a*). This corresponds to a conical depression in the stockline of a furnace of circular cross-section. When the height of the stockline was maintained constant the internal descent of granules was practically on a straight front, i.e. as a disc in a furnace of circular section (Fig. 5*b*). These flow patterns were practically unchanged when an obstruction or dead man was placed in the hearth.

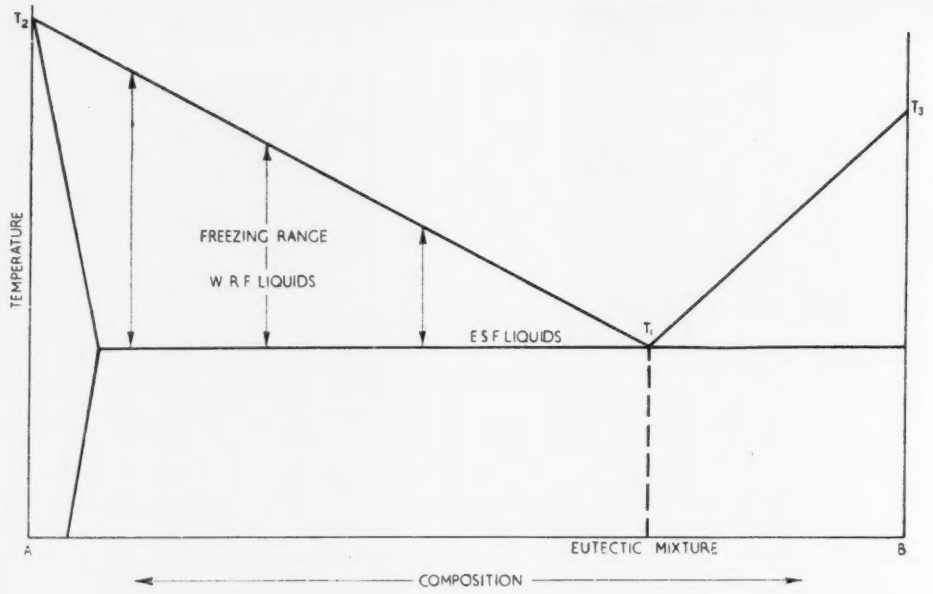


Fig. 6—Eutectic diagram, showing variation in freezing range

It is important to note that the flow was not blocked unless the granule size was markedly increased. In other words, at the normal ratio of particle size to furnace diameter, hanging cannot occur unless extensive agglomeration of the granules takes place, forming a strong arch or dome.

Lining Failures due to Phase Changes

Wear, hanging, and scaffolds are complicated mineralogically and chemically but, except for abrasive wear in the top dry zone, they are all caused by *simple* phase changes in the charge and in the refractory. The two-component diagram (Fig. 6) illustrates that the change from liquid to solid, i.e. *freezing, is produced over a wide temperature range in all compositions except those near pure components and eutectics.* This relationship is true, even in the most complex systems.

In Fig. 7 liquids are classified into these two categories: W.R.F. (wide range freezing) and E.S.F. (eutectic sharp-freezing).* Thus the refractory may undergo only four possible changes: it may convert

* This broad classification into two types of liquid makes it unnecessary to specify actual chemical compositions. All slags are multicomponent systems in which E.S.F.'s are produced between 700° and 1000° C. All commercial firebrick refractories, even when uncontaminated, have a small percentage of components such as titania, lime, magnesia, and alkalis which form a small amount of E.S.F. liquid in the same temperature range. Miscible W.R.F. liquids are formed when either of these systems is heated to higher temperatures.

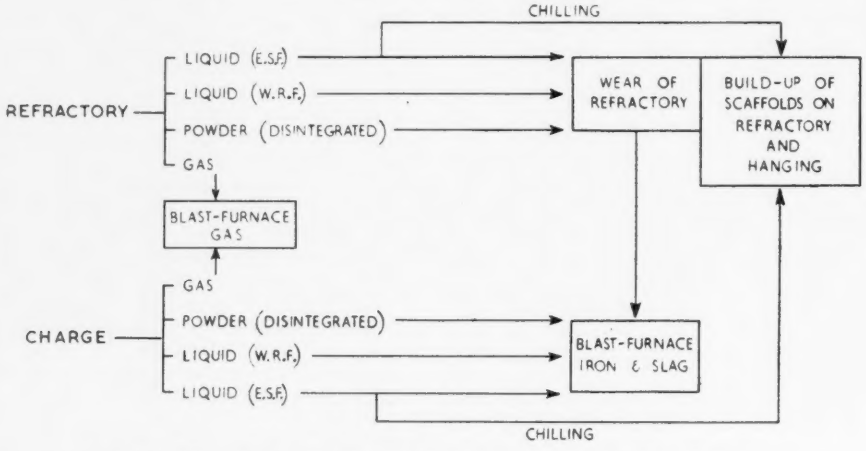


Fig. 7—Results of phase changes in the charge and in the refractory

to gas, disintegrate to a powder,* or form one or other type of liquid. Inevitably these phase changes result in slag and iron making from the charge, and *wear* of the refractory. If the furnace chills, iron, slag, and wear are still produced from the W.R.F. liquids, but not from the E.S.F. liquids, which will set solid.† This freezing of liquid between the lumps of charge and on to the refractory can lead to hanging and to two distinct types of scaffold. Hanging (Figs. 8*a–c*) results from chilling, so that a solidified arch of charge is formed strong enough to support the material above it until increasing forces or rising temperatures cause the obstruction to collapse, and a furnace slip occurs. When such an arch does not come away cleanly, an *arch-residue* type of scaffold is left which is typified by a cemented granular structure (Fig. 9*a*). By contrast, when films freeze successively and repeatedly *on the refractory walls*, a different and laminated type of scaffold is gradually built up layer by layer (Fig. 9*b*). Each succeeding layer thermally insulates its predecessors. Structures intermediate between arch-residue and laminated types of scaffold result from the adventitious trapping of solid particles in the setting liquid films. Most scaffolds are of the arch-residue type.

The model shows that, *provided there is no extensive agglomeration* of the charge, even extremely large model scaffolds do not reduce the working diameter seriously enough to obstruct adequate flow. This seems to offer a feasible explanation for the record outputs which are sometimes obtained shortly before 'blowing-out' a furnace in which a large scaffold is discovered. It should be noted that an arch-residue scaffold could be produced in a very short time and could have occurred just before or even during blowing-out. A large laminated scaffold, on the other hand, requires a long time to build up.

Wear, scaffolds, and hanging are outlined in more detail in the Appendix but, before proceeding to the main proposals arising from the present investigations, a brief account is given of the current methods of dealing with these defects.

Existing Control of Wear, Hanging, and Scaffolds

The destructive chemical processes leading to wear of the refractory occur at fairly high temperatures—carbon disintegration takes place at about 500° C, alkali disintegration at about 1000° C, and solution by W.R.F. slags at higher temperatures. Two approaches have been made to solve this problem: a search for refractories that will be more resistant

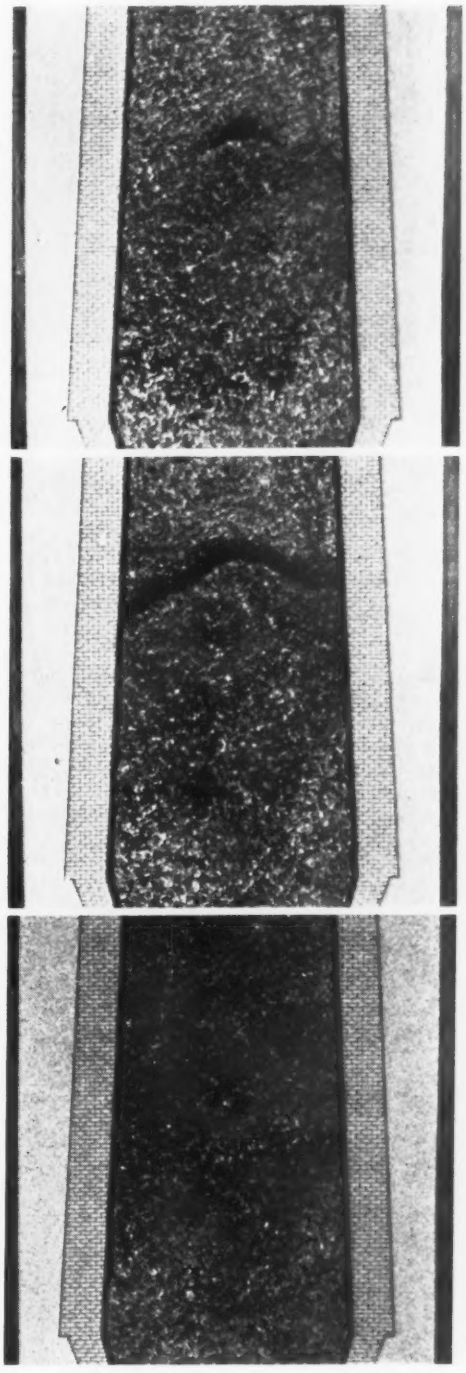


Fig. 8—Hanging and slipping

* Disintegration of fireclay blast-furnace refractories may be caused by several agencies: (1) *thermal shock*, which is not commonly encountered; (2) *attack of carbon monoxide*, $2CO = CO_2 + C$, in which internally deposited carbon disrupts the structure at very low temperatures (about 500° C) when there is no liquid phase; (3) *attack of alkalis*, alkalis entering into the liquid phase about 1000° C and penetrating the pores of the cooler zones of the brick appear to expand and break up the brick. (There is an extensive literature on carbon monoxide and on alkali disintegration.)

† Setting may be due either to the viscosity of the E.S.F. liquid increasing to form a practically rigid glass, which may crystallize later, or to immediate crystallization. Both of these occur far more readily in an E.S.F. than in a W.R.F. liquid.

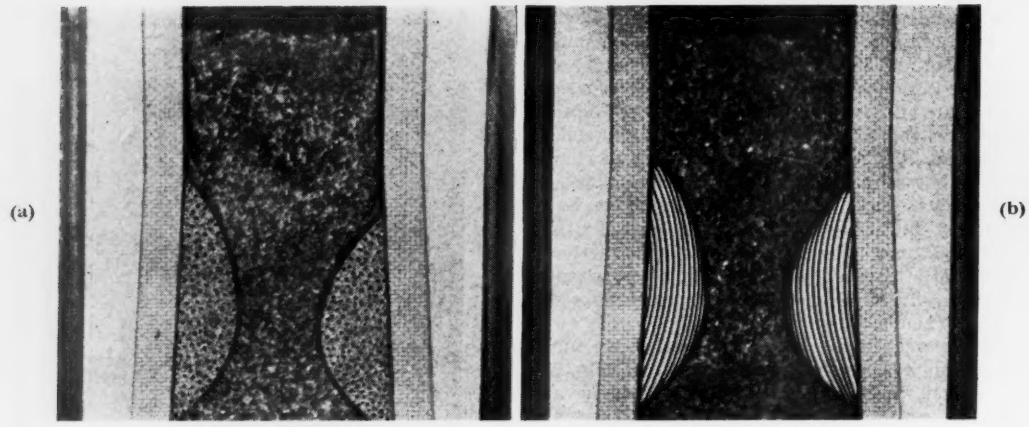


Fig. 9—(*a*) Arch-residue scaffold; (*b*) laminated scaffold

to these actions at the temperatures concerned, and the use of cooling to keep the working-face temperature below the danger levels.

For many years constant efforts have been made to improve the chemical or physical properties of the refractories. As already indicated, the two materials in common use are firebricks and carbon blocks. It seems unlikely that carbon will be surpassed for use in the hearth and bosh. Highly aluminous refractories have been on trial from time to time without spectacular results. More recently developed types of refractory such as carbides, nitrides, sulphides, silicides, etc., in addition to being prohibitively expensive, are liable to oxidize, particularly in the middle stack. Refractory metals offer no hope of survival because of contamination, oxidation, and cost.

The problem has resolved itself into making the best use of carbon and of firebricks or other oxide refractories by improving their physical properties, particularly to reduce their porosity and permeability in order to minimize the area of invasion by gas or slag, and therefore to diminish the rate of attack. The modern trend is in this direction, though the present minimum values of porosity of 10–15% still leave room for improvement.

Materials of construction need not be refractory if the temperature of the walls is kept low enough by *cooling*. The thermal resistance of ceramic material is so high (Fig. 10) that unless the lining is very thin the 'hot' face temperature cannot be lowered significantly by improving the cooling of the 'cold' face. The use of water cooling behind several feet of brickwork is quite useless, at least until the lining has worn back to an inch or so in thickness. In Czechoslovakia a number of water-cooled metal stacks, without any refractory lining, were in operation for

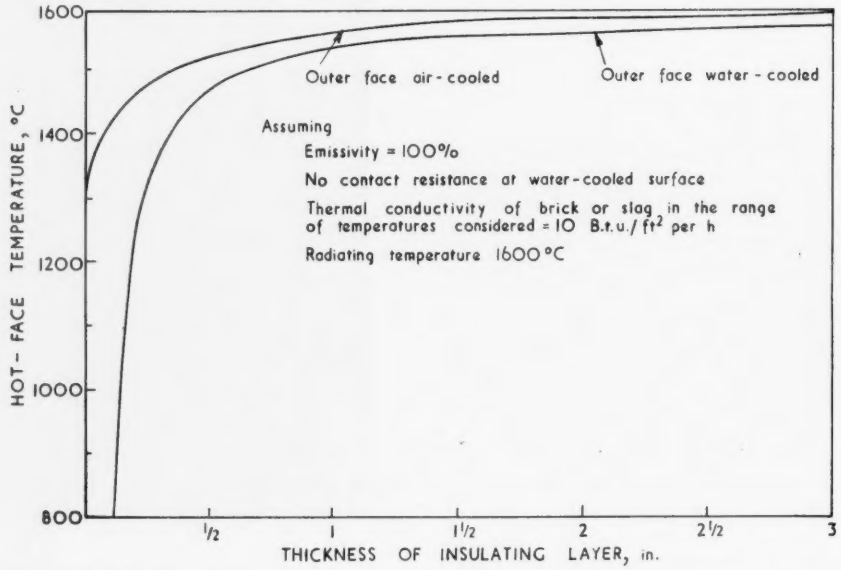


Fig. 10—Comparison of hot-face temperature (air *v.* water cooling) for different thicknesses of refractory or slag

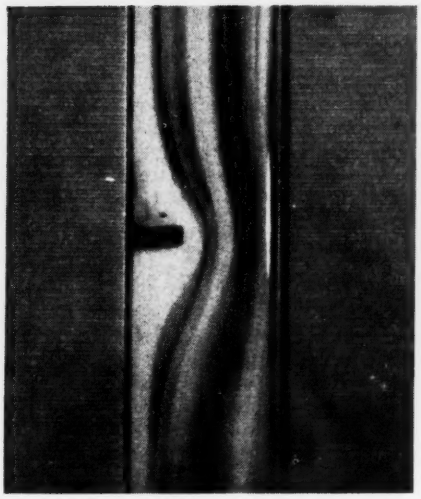


Fig. 11—Water flow past single obstruction

some years as a war emergency[1] apparently without intolerable heat losses. However, in view of the inevitably greater loss of heat this is not a solution to be recommended. While water cooling will not protect the refractory at any appreciable distance, it can, if efficiently applied, protect the metal of the shell, or of the projecting coolers, for very long periods.

In extreme cases hanging and scaffolds have caused furnaces to be blown out, but sometimes these troubles have been effectively dealt with by the use of coke charges, soda slugs, or even explosives.

Part II—PROPOSAL FOR A SELF-LINING BLAST-FURNACE

The foregoing discussion has shown how certain mechanical defects of the blast-furnace—scaffold formation, wear, and hanging—are the result of phase changes, both in the charge and in the refractory, and that these changes and the consequent troubles would persist whatever refractory is used in the structure. It was therefore thought desirable to try to develop a furnace which would be independent of built-in refractories. This novel brickless construction utilizes the refractory nature of the charge. It is based on the fact that granular material can serve as a refractory if it is held in position under compression. Thus material from the burden* may be used as a lining if it can be held on the walls and if it develops suitable properties.

The furnace design suggested was developed, using models where appropriate, to study:

(1) The flow of material through containers
(2) The chemical properties of static material
(3) The physical behaviour of static material.

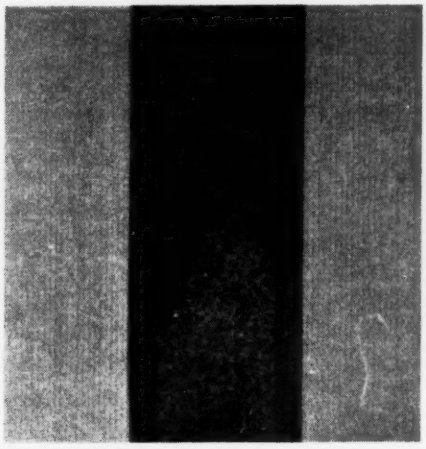


Fig. 12—Granular flow past single obstruction or shelf

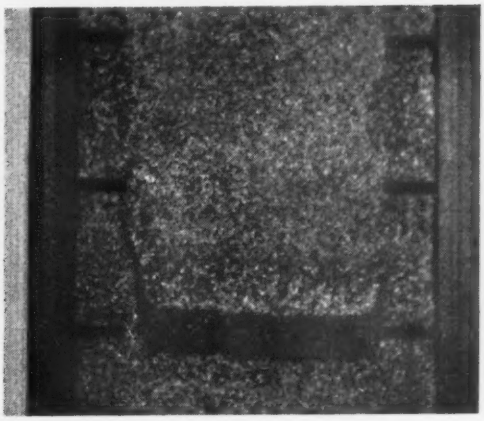


Fig. 13—Granular flow past numerous shelves (in straight pipe)

* It is worth noting that blast-furnace slag is ' refractory ' up to temperatures of 1300° C or more.

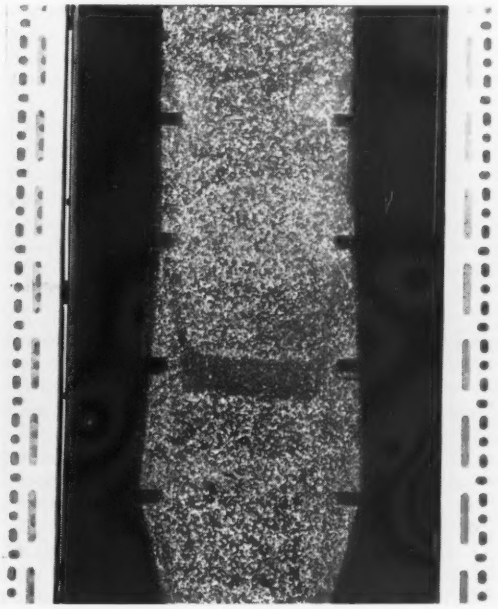


Fig. 14—Granular flow past numerous shelves (in blast-furnace-shaped pipe)

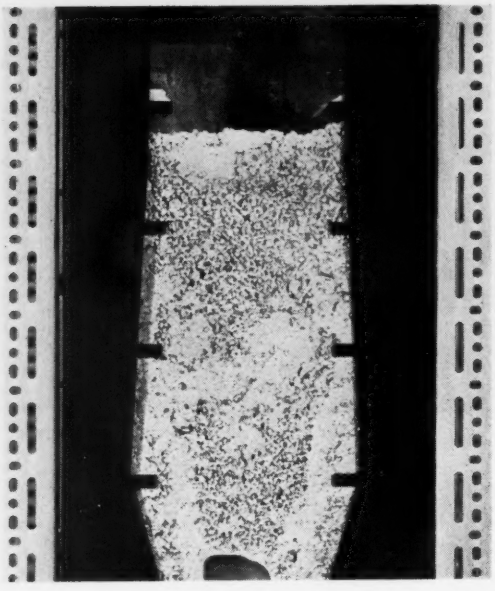


Fig. 15—Cavity at tuyeres

Material Flow

As the present aim is to hold a layer of material static on the walls, it is logical to try to do this by placing a fixed obstruction or shelf in the path of flow. Such a shelf, in a liquid like water flowing at low speeds (i.e. in streamline, not turbulent flow) results in almost stagnant triangular zones fore and aft, which are only slightly disturbed by recirculation (Fig. 11). The higher the internal friction (i.e. viscosity), the more these recirculating eddies become damped out. With a granular material, which has very high internal friction, similar but completely static zones occur before and after a shelf. These zones can be seen as dark triangular areas in Fig. 12.

When additional shelves were inserted in series in the parallel-sided model, a continuous static layer of any desired thickness and shape was produced (Fig. 13). On making the channel the shape of a traditional blast-furnace, a similar fixed layer was evident under downward flow conditions (Fig. 14). It should be noted that the internal advance of granules in approximately parallel-sided pipes is on a straight front (compare Figs. 7, 13, and 14). It should be appreciated that the shelves do *not* result in a noticeably corrugated flow line, owing to the almost straight inner edge of the static zone. Thus no hanging (i.e. no impediment to flow) is produced by this type of construction. In fact as already indicated very large scaffolds, equivalent to very large shelves, do not of themselves prevent adequate flow. When other movements, arising from checking the furnace, were simulated by injecting the blast through tuyeres and using lightweight granules in the model, the whole contents rose very slowly (blast on) and fell quite sharply (blast off). The upward and downward movement was clearly due to the formation and collapse of a large cavity at the tuyeres and not to the separation of granules, which always remained closely packed (Fig. 15); i.e. they were not fluidized, as gas flow rates were too low. *None of these movements disturbed the material between the shelves.*

Since these experiments demonstrated that, under flow conditions simulating those occurring in the blast-furnace, materials could be held static on the walls by annular baffles, it remained to consider what chemical and physical properties would be developed in the static layer.

Chemical Properties of Static Material

The material trapped initially between the shelves can be considered as a mixture, some constituents of which are relatively stable, and some of which are unstable, under the various local conditions. The reactions of the unstable components are those already shown to result in wear (Fig. 7), i.e. the trapped granules change to gas, disintegrate to a powder, form W.R.F. liquid, or form E.S.F. liquid, *except that the second of these, disintegration, does not lead to a loss* when the now granular solid is trapped by the shelves. The loss of unstable components, and replacement by a mixture of stable and unstable materials, ultimately results in the survival of stable constituents alone between the shelves. In practice the components in these deliberately formed 'growths' will vary for different zones in the same way as those in normal scars and scaffolds. The chemical constitution of *static* material at different heights is described in the Appendix and summarized in Table I.

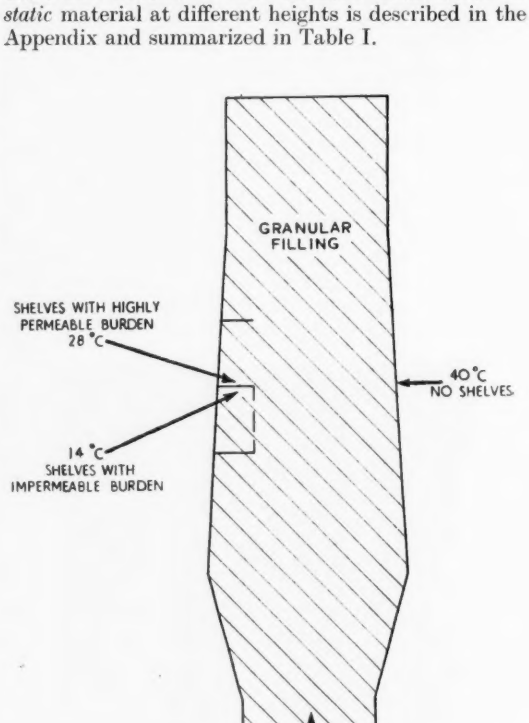


Fig. 16—Effect of shelves and impermeability on heat loss

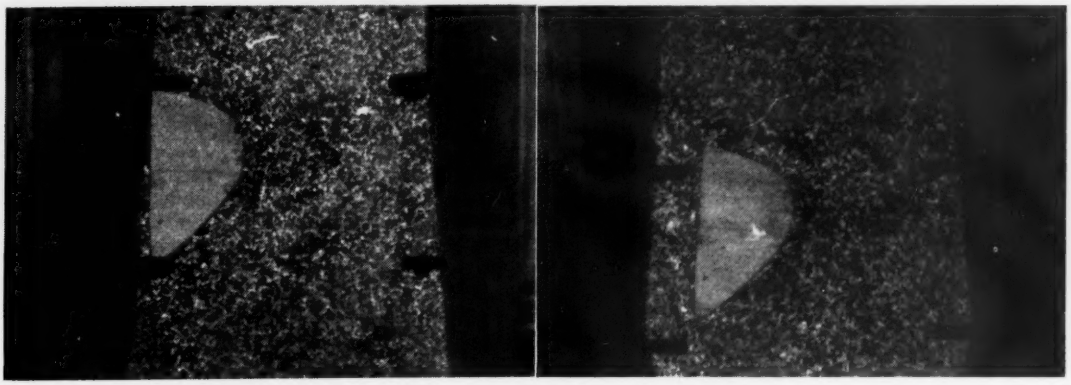


Fig. 17—(*a*) Scaffold fixed by roots between shelves; (*b*) hypothetical unrooted scaffold descends with burden

Physical Properties of Static Material

In the course of time the material trapped at different heights between the shelves will assume the same hard, impervious, strong properties as the scaffold materials described in the Appendix (p. 43).

The model was used to examine the effect of the shelves and of the physical nature of the material trapped between them on the heat transfer to the outside wall. These experiments used a ' hot ' blast (about 80° C), and measurements of shell temperature were taken to provide an indication of heat loss under three conditions. Without shelves the wall temperature was 40° C above room temperature, with shelves confining *porous* material it was 28° C, and with shelves containing similar granules, rendered *impervious* by a copper septum, it was 14° C (*see* Fig. 16).

Summing up, this examination of the flow of material in a furnace fitted with baffles and of the properties of trapped material shows that wear can be circumvented by a *suitable self-renewing lining*. It remains to consider the effect of such a shelved construction on the occurrence of hanging and scaffolds.

The Use of Stack Tuyeres to Control Hanging and Scaffolds

The behaviour of scaffolds was studied on the model since growth would be just as likely to occur on the shelved lining as on brickwork. Water cooling of the shelves would not increase the tendency to form scaffolds because of the short distance over which cooling has any significant effect. There was a possibility that, even though scaffolds could begin to grow, they could only develop to a limited extent before being torn off by shear forces due to the moving burden, in view of the lack of bonding to the cold metal shelves or wall. ' Large ' model scaffolds were placed ' free ' in the furnace to represent the actual absence of bonding. Two positions were adopted, one with the root of the scaffold inside the edge of the shelves (Fig. 17*a*) and the other with it outside (Fig. 17*b*). The latter was a hypothetical case since, in service, high temperatures would consolidate the root within the shelves. The scaffold in this position moved right down the furnace. However, when the root projected into the shelf recess, as it would in practice, there was *no dislodgement*. In consequence indirect methods of scaffold control have to be envisaged. While the ' checking ' of a furnace would appear to reduce the chance of scaffold formation, the real remedy lies in removing the cause of both growth and hanging, i.e. in preventing chilling. This could be done by intermittently injecting a small amount of air through special stack tuyeres (Fig. 18). These need affect only regions near the walls at *levels* where sharp-freezing liquids exist, and a *few degrees* temperature-rise would suffice, because of the eutectic nature of the liquids formed at this stage.

While local, and temporary, high temperatures due to this additional air could be disastrous to brickwork, they would actually strengthen the deeper layers of the self-renewing lining by causing sintering.

Practical Considerations

Water cooling of the *shelves* is essential, but it could be avoided for the *shell* if an initial brick lining were installed. This would have the additional advantage of eliminating any risks in a trial installation, which would at worst give a normal life and at best a very long campaign.

The extent of the proposed water cooling is not abnormal so that no new problems are introduced. Calculated heat losses for a typical shelf system amount to no more than 0·5% of the total heat input to the furnace. Past experience has shown that coolers, if efficiently designed, can last for 20 years or more; this is not surprising in view of the superior abrasive resistance of a *cold* metal compared with a hot, partly liquid refractory. Renewal of cooling elements during operation is possible. In addition, repeated instances are quoted in a " Survey of Blown-out Linings,"[2] not only of the way in which the surfaces exposed to the flow of the charge are bared, but also of burden material being trapped above and below them. This confirms the basic assumptions of the present design, that *the coolers do not have a significant cooling effect on the refractory, and that they act as efficient baffles.*

The thickness of the lining is controlled by the distance to which the shelves project into the furnace. The model work suggests that the vertical distance between the shelves need not be closer than about

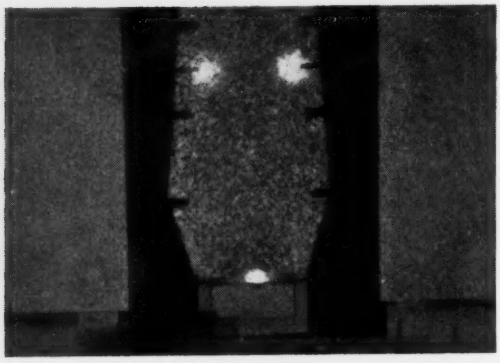


Fig. 18—Stack tuyeres proposed for prevention of hanging and scaffolds

five times their width. There is no engineering difficulty in providing shelves of adequate strength to withstand the forces acting on them, nor in making it possible to replace faulty shelf units. This system should permit operation with linings that are thinner than usually necessary, thereby increasing the working capacity of the furnace.

In Czechoslovakia[1] gradual practical development of thin-walled furnaces over the past 20 years has reached the point where a trial of a similar shelved construction with intervening brickwork is now being planned (Fig. 19). Recent Russian developments,[3] using brick linings and extensive cooling both of ledges and of the outer wall, were aimed at locking-in the brickwork rather than utilizing the burden material. However, examination of this Russian furnace, when it was deliberately blown out at several very early stages, revealed that in many places the brickwork had quickly disappeared and the shell was protected by material from the burden.

Tuyeres placed at higher levels than usual are in operation in some furnaces on the Continent. Their installation in positions just below the scaffold-prone level presents no new problems. A detailed programme for operating stack tuyeres could be developed in practice, and designed preferably to prevent, or alternatively to cure, scaffolds and hanging. For prevention, the periods of air injection should be short (about 1 h), to localize the heating effect, and repeated as a routine at regular intervals to keep the furnace running smoothly. The intervals might vary from a few days to some weeks. In view of the small amount of heat required, no extra fuel is necessary.

To cure existing hanging or scaffolds, much more

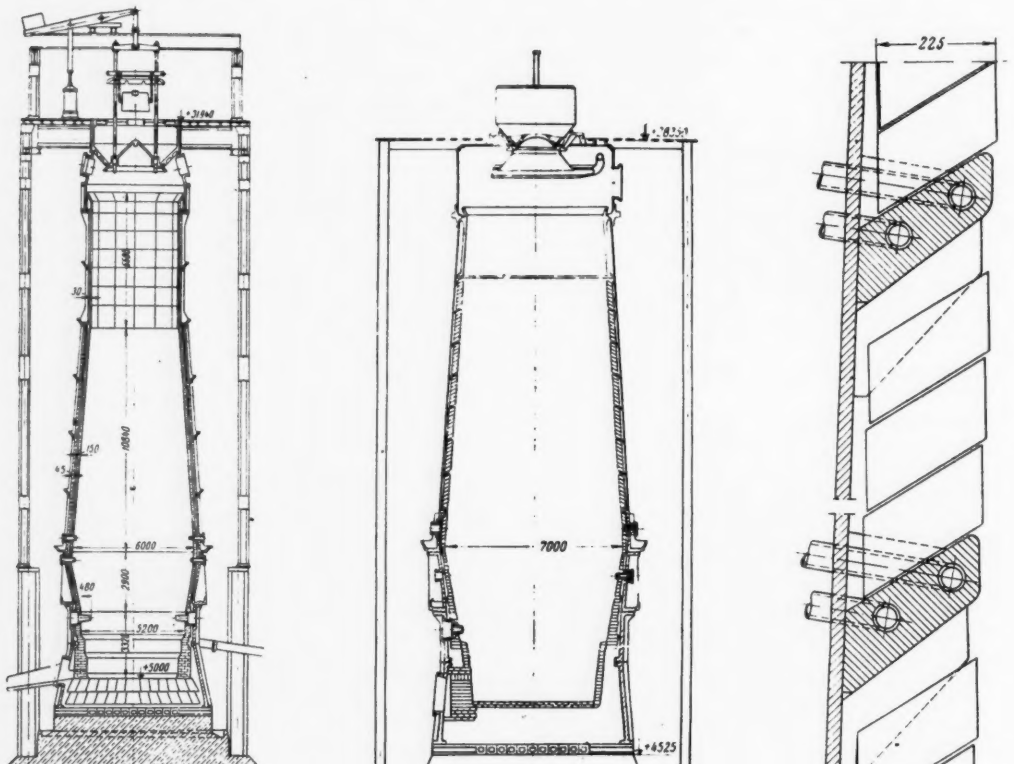


Fig. 19—Development of thin-walled furnaces in Czechoslovakia

frequent injection would be required, under supervision, and the additional fuel then required would be introduced either as oil or gas through the tuyeres or charged at the top as extra coke. While the resultant local and temporary high temperatures would sinter and strengthen the deeper layers of the self-renewing lining, they could be disastrous with brickwork, for which this technique is not recommended. Uneven and irregular working would be less likely with these arrangements, but if they occurred to any marked extent they would have no ill effects, but merely make the character of the lining zones at different heights somewhat unsymmetrical and changeable. To sum up, this shelved construction with stack tuyeres offers a good chance of solving the problems of wear, hanging, and scaffolds and therefore would seem to merit practical trials. These could be devoid of risk if brickwork were initially installed, and yet offer greatly extended efficient operation after the original lining had failed.

SUMMARY AND CONCLUSIONS

Brick-lined Blast-furnace

The flow of granules through the blast-furnace has been studied by means of models. Hanging has been shown to be caused by the same feature that produces scaffolds, i.e. the *chilling*, in the region where they occur, of eutectic sharp-freezing liquids. The metal laminations in the scaffolds have been explained by a process of concentration of iron by reduction and precipitation from these liquids. The absence of carbon in this iron is due to it being protected from contact with the gases or the coke by liquid slag films.

It has been demonstrated that wear under the scouring action of the charge is serious when the refractory is deteriorated by liquid slag attack, by carbon monoxide or alkali disintegration, or when there is no liquid slag at all to act as a lubricant.

Self-lining Blast-furnace

As a result of model work and theoretical considerations, a system of blast-furnace construction has been proposed to counteract wear, scaffolds, and hanging. The salient characteristics of this design are water-cooled shelves and stack tuyeres. It is thought that by the joint use of these devices the life of the furnace would be increased considerably and substantial financial saving would result.

APPENDIX

Detailed Consideration of Scaffolds and Hanging

Severe wear on the walls takes place by scouring action when deterioration of the refractory is caused by phase changes producing gas, disintegration, or excess liquid. Growth results when these phase change reactions go in the reverse direction owing to some action such as chilling. A prerequisite of growth in face of the scouring action of the burden is '*sticking*' of the deposited solid to the wall or scaffold surface. This adherence is influenced by compatibility. The solid growths observed by Rigby[4] on normal oxide refractories are:

(*a*) Oxide slags, which would be expected to bond to such bricks

(*b*) Iron, in the form of laminations or powder, which is an example of the familiar 'cermet' bonding

(*c*) Carbon, which may be mechanically trapped.

Deposition of solids from a gas would produce a continuous film over the surface of the walls. The manner of deposition of a solid from a liquid would depend on whether or not the walls were wetted. When the liquid wets the solid or is miscible with any liquid contained in the wall it will spread over the surface as a continuous film. If the liquid does not wet the wall it will be present on the surface as isolated globules and therefore in smaller amount. Solids will be formed on the wall from the liquids accordingly.

Chemical Reactions

The reversible chemical reactions of importance in these phase changes causing wear, hanging, and scaffolds are not numerous. They are

$$2C\ (\text{solid}) + O_2 = 2CO\ (\text{gas}) \quad \ldots\ldots(1)$$

$$2CO\ (\text{gas}) = C\ (\text{solid}) + CO_2 \quad \ldots\ldots(2)$$

$$Fe^{++}O^{--}\ (\text{in liquid slag above } 700^\circ\text{C}) + C\ (\text{All these at } 800^\circ\text{C in the furnace are almost equivalent reducing agents}) = Fe\ (\text{Solid metal up to } 1535^\circ\text{C when pure}) + CO\ (\text{and alkali disintegrate firebrick}) \quad \ldots\ldots(3)$$

$$Fe^{++}O^{--} + CO = Fe + CO_2 \quad \ldots\ldots(4)$$

$$Fe^{++}O^{--} + 2K^{*} = Fe + K_2O \quad \ldots\ldots(5)$$

In addition to these, there is the general fluxing action due to high temperatures producing liquid slag.

Physical Conditions and the Chemical Reactions

The furnace can be visualized as having a completely dry or arid zone in the top 20 ft, where temperatures are above 100° C (so that there is no liquid water) and below about 700° C (where there is no liquid slag). From this height down to approximately the bottom of the stack, the sole existing liquid is slag; some distance below this level iron also becomes liquid. Liquid iron is immiscible with liquid slag. These liquids are draining down through the mass of granules and over the surface of the wall. The rate of liquid formation and of liquid draining down through the charge and on the wall increases towards the bottom of the furnace where the temperatures are higher. There is no lack of time for the reactions of static materials, in scaffolds or held by shelves, to reach equilibrium.

The gas atmosphere in which these reactions take place, is indicated by the 'mean blast-furnace gas' line in Fig. 20[5] which, when compared with the other oxygen potential curves, shows that

(1) Carbon bricks burn in the middle of the stack

(2) Carbon is deposited in the higher parts of the stack in the presence of a catalyst such as iron, to cause carbon disintegration of firebricks

(3), (4), and (5) Iron oxide is reduced to metallic iron at *all* levels.

Thus solid iron at temperatures below its melting point (pure iron: 1535° C) is precipitated from the iron-oxide-containing liquid slag films. This deposition builds up quite thick metal laminations on walls during long periods of even working. Any particles of trapped iron ore are reduced to form less concentrated powdered iron (e.g. in arch-residue scaffolds). The alkalis, zinc, etc.

* Above 800° C the alkalis are reduced to the elements by carbon and the furnace gases. Zinc behaves in a similar way to the alkali metals.

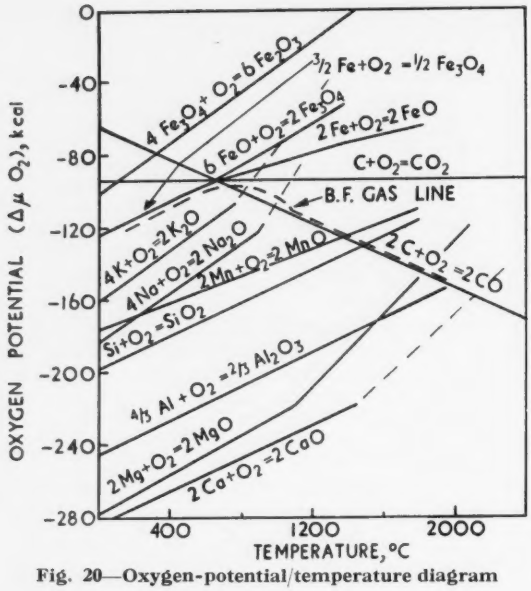

OXYGEN POTENTIAL (Δμ O2), kcal
TEMPERATURE, °C
B.F. GAS LINE
4 Fe3O4 + O2 = 6 Fe2O3
3/2 Fe + O2 = 1/2 Fe3O4
6 FeO + O2 = 2 Fe3O4
2 Fe + O2 = 2 FeO
C + O2 = CO2
4 K + O2 = 2 K2O
4 Na + O2 = 2 Na2O
2 Mn + O2 = 2 MnO
2 C + O2 = 2 CO
Si + O2 = SiO2
4/3 Al + O2 = 2/3 Al2O3
2 Mg + O2 = 2 MgO
2 Ca + O2 = 2 CaO

Fig. 20—Oxygen-potential/temperature diagram

present in the charge will be reduced to the metals at all temperatures above about 800° C, and will accumulate in clouds at levels corresponding to their boiling points (Fig. 21).

This build-up of a concentration of alkalis during the whole operation of the furnace is due to the closed circuit provided by the downward carrying action of the charge on condensed alkali, and the upward carrying action of the furnace gases, on the vapour formed when they boil.

The metal (or cyanides) penetrating through the pores of the refractory or of the scaffold reach colder zones where they may be re-oxidized and react to form alumino-silicates (which cannot later be reduced in the furnace). This combination with brickwork may lead to its disintegration, so that a *gain* of material, alkali, as with carbon, can lead in the end to a severe *loss* of refractory.

Scaffolds are formed by setting of E.S.F. liquids, and alkali oxides enter into them because, with the boiling points of the elements around 900° C, they accumulate and later oxidize in the regions concerned. The effect of alkalis is not to *cause* scaffolds, but to produce E.S.F. liquids higher up in the furnace than would otherwise have been the case.

It has already been shown that E.S.F. liquids account for scaffolds and that W.R.F. liquids account for wear by slag attack low down in the furnace. The W.R.F. liquids, from the hearth up to some way into the bosh, are above their liquidus, i.e. they are unsaturated, and so will readily dissolve refractory material.

Low Carbon Content of Iron in Laminations on Walls and Scaffolds

The iron in the laminations contains practically no carbon (0·05%) although, at the temperatures concerned, it should pick up about 5% from the solids or the gases. The iron oxides in the film of liquid coating the furnace wall are reduced at the film/gas surface to form metallic iron particles. These diffuse back to the wall *protected from carbon monoxide gases and solid carbon by the liquid slag film which accounts for the absence of carbon in the iron*. The protection is due to the fact that carbon is not soluble in the liquid slag film. Infrequent exposure of the metallic iron directly to carbon or gases and the sluggishness of the solution of carbon in solid metal at the temperatures concerned provide very little chance of carbon pick up.

Relationship between Position in Furnace and Composition of Scaffolds

All these factors result in characteristic compositions of scaffolds at various heights, summarized in Table I.

Comparison with Rigby's Theory of Scaffolds

In 1949 Rigby[4] proposed a theory to account for the formation of scaffolds which differs essentially in the

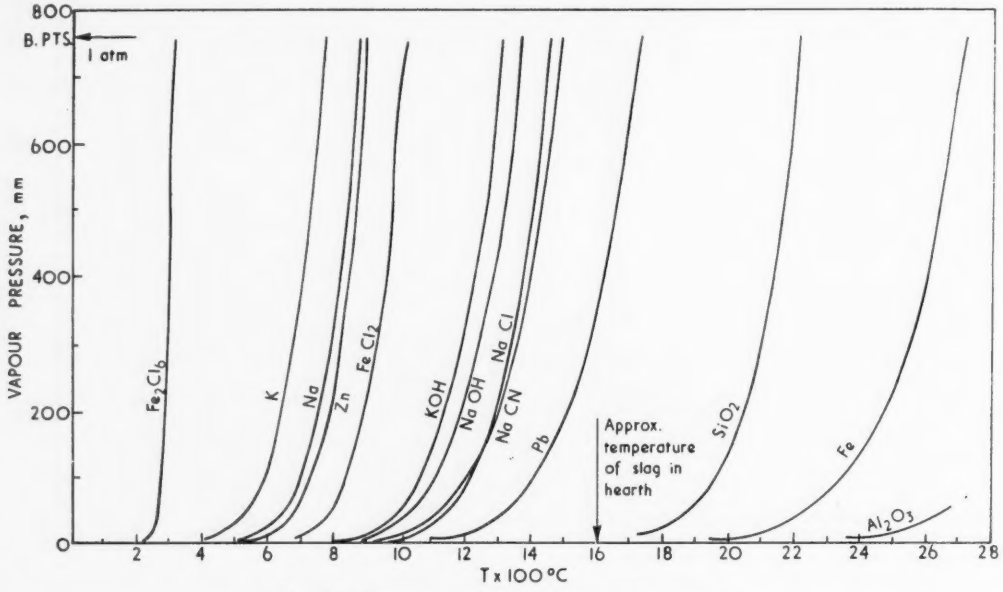


Fig. 21—Vapour-pressure/temperature curves

Table I

COMPOSITION OF GROWTHS ON BRICKWORK AT VARIOUS HEIGHTS IN FURNACE

Position in furnace	Proportion of		
	Carbon	Oxides	Metal
Top	Medium	Large	Small (laminations or powder)
Middle	Small	Large (containing up to 20% alkali)	Large (laminations or powder)
Bottom	Large	Large	None

following ways from the explanation outlined in this paper:

(1) Rigby makes the alkalis a prerequisite of scaffold formation, whereas the present theory considers *any* eutectic liquid can be responsible, and that it is incidental that alkalis condense at this level.

(2) In order to form scaffolds, the solid material must adhere to the viscous slag despite the continuous drag of the moving burden, and it would appear unlikely that a slow solidification process, such as the crystallization of kalsilite as proposed by Rigby, would be effective. The rapid setting of the E.S.F. liquids postulated in this paper seems to be a more suitable mechanism.

(3) Rigby suggests that, because of a throw-up of an alkali cloud, slips are responsible for the periods of intense or concentrated reduction, during which the iron is formed. This does not account for the marked *enrichment* of iron in the laminations and, in any case, a slip merely displaces the *same* alkali cloud from one level to another. In the present sharp freezing liquid theory, this concentration is simply attributed to reduction/precipitation of iron from liquid slag films.

(4) According to Rigby, the low carbon content of the iron is explained by the reduction of the iron oxide by alkalis. As this does not preclude contact with carbon and carbon monoxide, it does not explain the absence of carbon in the iron. The present theory accounts for the low carbon content by the protection of the metallic iron by the carbon-free slag films.

(5) Rigby's explanation for iron laminations in the scaffold associates them with abnormal operation. The sharp freezing liquid theory suggests that the reverse is true, i.e. that under steady conditions of operation iron oxide is continually reduced from the slag films and iron deposited on the walls.

(6) It seems reasonable to suggest that hanging is a short-lived scaffold, extending over substantially the full diameter of the furnace, so that both phenomena should have a common cause. The freezing-liquid theory complies with this. Rigby does not deal with hanging, but his alkali-accumulation theory does not fit here for the same reason that it fails to explain scaffolds, i.e. it could not account for sufficiently fast solidification.

Relationship between Position in Furnace and Prevalence of Hanging and Scaffolds

The zone in the furnace most prone to growths is the middle third of the stack, and it follows that this is also the region where hanging is prevalent. The extensive height of the zones is due both to the wide range of E.S.F. liquids, arising from the charge being heterogeneous and not too well mixed, and to the fluctuating temperatures. The very drastic chilling periods that would be necessary to solidify the W.R.F. liquids lower down the furnace are fortunately very rare, so that neither hanging nor scaffolds would be expected to occur in this position.

Relationship between Position in Furnace and Physical Properties of Scaffolds

The physical nature of scaffolds is dependent on the height at which they occur in the furnace. Some scaffolds (the laminated variety prevalent in the middle stack) are hard and tough owing to iron laminations, and are little changed by age. Those scaffolds, low in the furnace, which have a high coke and a low iron content are softer and more friable than those at higher levels. The increased hardness and the decreased permeability of the older arch-residue scaffolds are caused by the blocking of pores by gas-borne materials. Scars taken from various heights in a furnace after it was blown out were tested in the laboratory and found to be as impermeable as firebricks. While little direct evidence is available, it is obvious that a hanging arch in a furnace will be self-aggravating because, owing to blockage with gas-borne dust, the longer it remains the stronger it will become.

Relationship between Position in Furnace and Profile of Scaffolds

It has been demonstrated in the section dealing with the flow past a single obstruction that growths should tend to be symmetrical (Figs. 11 and 12). In fact, this is the case, except for scaffolds or scars near the top of the furnace which have an inverted nose profile. Some typical profiles are shown in Fig. 2. The unsymmetrical shape at the top is due not to the absence of a static zone, but to the absence of cementing liquid above a certain height, so that the granules fall away when the furnace is emptied. In this arid zone, free from liquid water or slag, there is neither hydraulic nor ceramic bonding.

Influence of Types of Material Charged on Hanging and Scaffolds

The requirement for hanging and scaffolds in the relevant zone is the existence of sharp freezing liquid slag films on most of the solid surfaces. These films will be present in furnaces operating any normal burden. The slag bulk varies widely in the U.K., from 4 to 26 cwt/ton. In the lowest proportions, it is possible that there is insufficient liquid to cause a furnace to hang. The variations of slag bulk would not appreciably affect the physical and chemical constitution of scaffolds. The use of sinter *per se* would be expected to influence neither the occurrence of hanging and scaffolds nor the chemical and physical properties of the latter.

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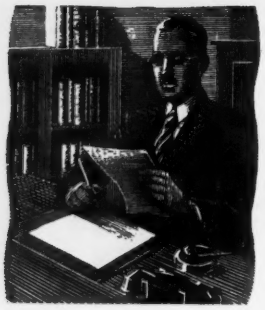


CORRESPONDENCE

Correspondence on Papers · Letters to the Editor

Correspondence on the Paper—

The Corrosion Resistance of Low-Alloy Steels*

By J. C. HUDSON and J. F. STANNERS

Dr. **E. Herzog** (Pompey, France) wrote: This paper summarizes a large number of investigations and draws clear-cut conclusions about the influence of small additions of various elements to steels on their resistance to atmospheric and aqueous corrosion. Information on this subject is widely scattered and often varies from author to author. Dr. Hudson and Mr. Stanners have done well to group and review all their results, thus enabling a clear picture of the problem to be obtained.

From the writer's own results it is possible to compare certain facts observed after the addition of aluminium and of chromium plus aluminium to steels.

Atmospheric Corrosion

The addition of aluminium reduced the corrosion rate in certain cases and increased it in others (*see* Table *A*). In Paris and Lille the action of aluminium in 2–4% chromium steels was favourable, whereas in the Pompey works it accelerated the corrosion (*see* Table *A*).

This difference can be explained by the properties of the corrosion products formed. Aluminium makes the rust more hygroscopic and more voluminous. With alternate drying and wetting (continental climate) these differences in volume help the corrosion products to become detached. In an atmosphere of high humidity and with less extreme variations, the corrosion products may adhere better and offer some protection.

Figure *A* shows the results obtained in the damp acid atmosphere of Lille after 3 years' exposure horizontally, vertically, and inclined at 45°. The action of the additions depends on the rate of drying. Exposure in the horizontal position gives the least satisfactory results.

Corrosion in a Marine Atmosphere

Thanks to the kind help of the International Nickel Company and the friendly interest of Mr. F. L. LaQue, the writer has been able to carry on long-term tests at Kure Beach since 1948. Figure *B* shows the variation with time of the rates of corrosion of the chromium and chromium–aluminium steels.

The effect of aluminium is less than that of chromium, but it is, nevertheless, of the order of about 20%. These tests were made at a distance of about 100 m from the water's edge.

Other tests, in progress since July, 1953, show the action of aluminium more clearly. Very close to the water's edge, when exposed to the spray, its action is very noticeable; on the other hand, further away, in salty air, it is less pronounced (*see* Table *B*).

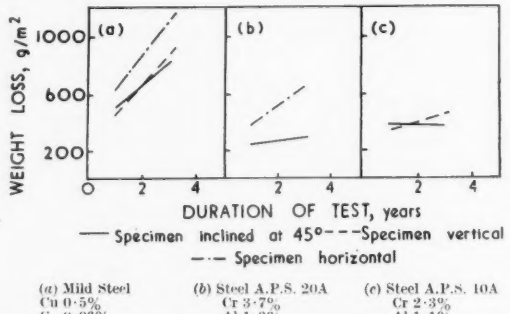
In the light of these results the influence of aluminium appears to depend on the degree of humidity and the

Table A

EFFECT OF ALUMINIUM ON ATMOSPHERIC CORROSION

Steel	Loss of Weight, g/m²	Relative Order of Merit, %
(a) Pompey Works: Exposure for 11 months (1936), inclination 45°		
Reference Steel: Open-hearth	200	100
Basic Bessemer	196	98
0·5% Cu	141	72
0·4% Cu, 0·4% Cr	132	67
0·12% P	137	70
2·6% Al	316	162
4·4% Cr	78	40
2·3% Cr, 0·5% Al	145	74
2·4% Cr, 0·95% Al	161	82
0·9% Cr, 0·8% Si, 0·4% Cu, 0·12% P	120	60
(b) Pont de l'Europe, Paris: Exposure for 12 months to locomotive smoke		
Reference Steel: Open-hearth	600	100
Basic Bessemer	700	116
0·4% Cr, 0·4% Cu	480	88
0·5% Cu	500	83
2% Cr, 1% Al	433	72
4·4% Cr	310	51
4·8% Cr, 0·5% Al	200	33

*J. Iron Steel Inst., 1955, vol. 180, pp. 271–284.



(*a*) Mild Steel Cu 0·5% C 0·06%
(*b*) Steel A.P.S. 20A Cr 3·7% Al 1·3% C 0·37%
(*c*) Steel A.P.S. 10A Cr 2·3% Al 1·1% C 0·12%

Fig. A—Atmospheric corrosion tests at Lille: bare plates, sand-blasted

Table B

EXPOSURE OF CHROMIUM STEELS FOR 370 DAYS AT KURE BEACH; INCLINATION 30°

Steel	Distance from Sea, m	Loss of Weight, g/m²	Depths of Pits, mm	
			Max.	Min.
3·5% Cr	24	1590	0·76	0·56
	240	209	Not measurable	
4% Cr, 0·8% Al	24	510	0·25	0·18
	240	151	Not measurable	

Table C

RESULTS OF SEA-WATER IMMERSION TESTS AT KURE BEACH AFTER 1402 DAYS

Steel	Surface condition	Loss of Weight		Depth of Pitting, mm	
		g/m²	mm	Max.	Av.
Mild, killed	Sand-blasted	3500	0·47	1·78	1·09
	Sand-blasted and tar-painted	1122	0·15	1·32	1·02
2% Cr, 1% Al	Sand-blasted	2804	0·37	1·07	0·76
	Sand-blasted and tar-painted	1822	0·24	0·965	0·69
3·7% Cr, 1·3% Al	Sand-blasted	1262	0·17	0·56	0·40
	Sand-blasted and tar-painted	228	0·03	0·81	0·30
3% Cr	Sand-blasted	2103	0·28	>1·25*	1·25
	Sand-blasted and tar-painted	1542	0·205	1·25	0·46
5% Cr, 0·5% Mo	Sand-blasted	1963	0·26	3·1	1·52
	Sand-blasted and tar-painted	421	0·06	1·14	0·66

* Perforation of sheet specimens 1·25 mm thick; the other specimens 5·6 mm thick

extent to which it varies; it is only favourable when the humidity is high.

Corrosion in Sea Water

In immersion tests assessment is more difficult. It is important to be able, on the basis of the authors' tests, to decide with certainty that in this case aluminium is advantageous.

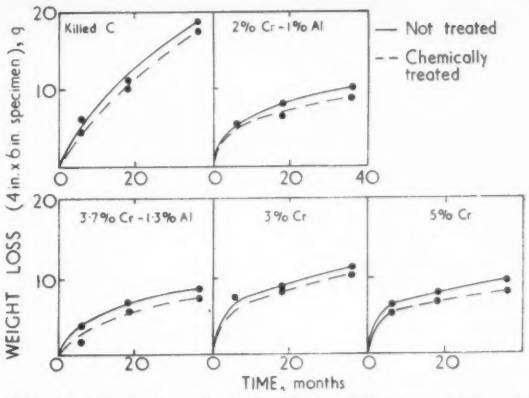


Fig. B—Corrosion of steels in marine atmosphere at Kure Beach

The writer's experiments, interrupted in 1939 by the march of events, were restarted by the International Nickel Company.

After 3 years' immersion at the depth of 1·80 m in calm water, the loss of weight of the steel with 3·7% chromium and 1·3% aluminium was one-third of that of the unalloyed steel. Similarly, the depth of pitting was only one-third or one-half of that of the comparison steel. On the other hand, the steels with 5% chromium were more deeply pitted than the comparison steel (Table *C*).

The problem of measuring the pitting and the interpretation of the measurements have been the subject of a number of researches and comments; since the writer's collaboration with Professor A. Portevin this aspect of corrosion problems has always been a live topic, and only partial solutions have been found. The measurement of the breaking load or of the electrical resistance of a wire certainly has advantages not possessed by the measurement of the topography of the surface, but unfortunately these methods are not applicable to flat products.

Positioning of Machine Dials decided by Human Eye Observation*

By R. B. Body

Mr. **R. G. Sell** (B.I.S.R.A.) wrote: Dr. Body describes in his paper a study he has carried out in his works to determine whether the screwdown dial should be placed in the mill pulpit or on the mill housing. This is a problem deserving attention but in case the conclusions put forward are held to be widely applicable I would like to make a few comments.

The main criteria by which the merits of each position can be judged are the presence or otherwise of fatigue or eyestrain. These are only likely to be present under experimental conditions if the subjects are exposed to the conditions for a considerable length of time. The subjects should be persons having the same visual characteristics as those normally employed in the mill, as it is possible that middle-aged men may suffer fatigue after a long period in which the eyes have to be continually and rapidly refocused. These aspects were not considered in the study described. Also, measuring changes in the diameter of the pupil does not reliably measure changes in accommodation.

Dr. Body assumes that the dial at present in use is the optimum size and has the optimum illumination. In fact, the results of experiments on dial reading indicate that a much smaller dial would be adequate for the accuracy required. This would mean that if the dial were placed on the mill housing it could be much smaller than the 22·25 ft dia. mentioned. Illumination of the dial would be much less of a problem than suggested as the only increase in illumination required would be to allow for the loss in transmission due to the glass in the pulpit.

There is no doubt that it is easier to clean a dial in the pulpit but before making any general recommendations on this point it is desirable that a more carefully controlled experiment should be carried out, considering the relative effects of the two positions on visual fatigue, eyestrain,

* *J. Iron Steel Inst.*, 1957, vol. 185, pp. 498–500.

and general fatigue as measured by a decrement in performance. We are hoping to do something on these lines.

AUTHOR'S REPLY

Dr. **R. B. Body** (Steel Company of Wales Ltd.) wrote: The points raised by Mr. Sell are of interest. It was noted with satisfaction that he feels that this is a subject worthy of further attention.

The problem was set originally as a purely operational one, and was therefore tackled as such. No doubt wider research on an experimental basis would be possible, mainly along theoretical lines. In this particular case, however, it was assumed that the dial of present proportions was operationally satisfactory. The workers after several years of usage were unanimous in their praise for this piece of equipment, and no single complaint regarding distance, size, or illumination had been received. It therefore seemed sensible to take this as a 'fixed point' for commencing observations.

Operationally, the dial receives purely casual scrutiny and its present large size appeared to be of considerable advantage for this type of observation.

Although measurement of fatigue might seem an alternative line of approach, the fact was realized that there is no known means of measuring fatigue, in spite of efforts which have been made to find one, especially in respect of airline pilots. Decrement in performance is not a practical means for measuring fatigue in air crews and is equally unsuitable for major pieces of industrial machinery. Measurement of pupil changes, in the circumstances and where casual observation only is required (as opposed to detailed observation), does present a practical and measurable entity applicable to this type of investigation.

In an integrated plant where the tonnage rate of the slabbing mill is a major factor for controlling the production of the whole plant, a Works Doctor has to conduct enquiries in such a way as to offer no interference with the actual operation, and where quality of the product has to be maintained a suggestion that decrement in performance would be a suitable yardstick was entirely out of the question.

Finally, the experimental subjects chosen were of different ages. Their corrected vision approached normal limits, as in fact the actual operators would, of course, be expected to possess.

The Potentiostat as a Metallographic Tool*

By C. Edeleanu

Mr. **M. Pražák** and Mr. **V. Čihal** (Research Institute for Protection of Materials, Prague, Czechoslovakia) wrote: The method of metallographic etching by controlled potential with the help of a potentiostat promises to become a very useful technique. This method will help to put the etching technique on a theoretical basis and to control the process of etching in this way.

This method makes it possible to determine in advance the conditions (especially the potential) suitable for the best differentiation of structural phases in the alloy. The method will also probably be useful for modification of the etching processes by chemical agents.

This method has already proved itself to be very suitable for determining the tendency to intercrystalline corrosion in stainless steels.[1]

For etching single phases of chromium–nickel steels the author used potentials in the region of activity and on the edge of the region of transpassivity. As we have shown in a recent work,[2] for differentiating phases with higher chromium contents (e.g. the δ ferrite and σ phase) in 18/8 steels, the region of secondary passivity of the austenite, which lies in 5% H_2SO_4 at the potential + 1·57 V (in relation to SCE), is also favourable. In this region of potentials, the differentiation ratio for these phases is a little higher than on the edge of the region of transpassivity. At the same time we pointed to the value of automatically registered polarization curves, which by themselves, without using a microscope, can indicate the presence of some phases.

For etching in the region of activity, an addition of 0·1 g/l. NH_4SCN (in 5% H_2SO_4) was found to be useful, as it speeds up the activation of chromium alloys, without disturbing the passivity at corresponding potentials.[3]

Next the author mentions the oscillation of potential occurring if a large resistance is incorporated in the circuit of potential-polarization. The origin of this oscillation can be given, as Schoen and Staubach[4] pointed out, by falling characteristic of the polarization curve in the region of passivation and low mutual conductance of the polarization source. Another reason for oscillations is the slow reaction of the potentiostat to changes of potential on the electrode being studied, which shows up especially if the electrode capacity is low (e.g. in the region of passivity).

AUTHOR'S REPLY

Dr. **C. Edeleanu** (Tube Investments Research Laboratories, Hinxton, Essex) wrote: It is very interesting to hear about the work carried out in Prague which seems to have been very similar to my own work. I agree with Messrs. Pražák and Čihal about the reasons for oscillations but I think that, with the instruments now available, difficulties will not often occur in practice except perhaps in conductivity water and this is not likely to be used in metallography. There are processes such as electropolishing in which oscillations can sometimes occur but then they reflect something actually happening at the electrode and the careful study of these oscillations may then be worth while, since this may throw some light on the electrochemistry of the process itself.

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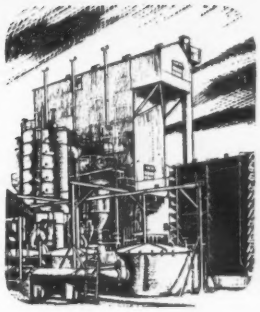
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



Report of the 32nd Engineers Group Meeting

THE THIRTY-SECOND MEETING of the IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on 5th December, 1956.

At the afternoon session a paper on " Positive-type Rotary Compressors " by Mr. V. Barnett (Hick, Hargreaves and Co., Ltd.) was presented by the author and discussed. The paper was published in the November, 1956, issue of the *Journal* (vol. 184, pp. 316–330).

POSITIVE-TYPE ROTARY COMPRESSORS

Mr. **T. Andrews** (The Nuclear Power Plant Co., Ltd.): On p. 316 of his paper, Mr. Barnett mentions eight principal advantages of the class of machine with which he deals. The second of these is that ' rotary motion eliminates fatigue in working parts caused by alternating stresses.' Since, however, the blades in the blade-type machine are alternately exposed to a differential pressure and no pressure, there is present, presumably, a fluctuating stress, the whole cycle from zero to maximum stress occurring once per revolution. Presumably the blade thickness and the materials are so selected that the maximum stress imposed lies well within the fatigue limit. It would be interesting to know whether or not there are records of blade failure, and, if there are, whether the brittle-rupture characteristics of fatigue failure have been noticed. In addition, it would be interesting to know whether blade deformation occurs, particularly with the restraining-ring type of machine with the relatively long unsupported blade length, and what effect, if any, this produces.

Of the rolling-drum compressor, would it be true to say that, other things being equal, this type of machine is capable of higher speeds than the restraining-ring design? If this is the case, is it made possible by the continuous blade support? In practice, does the difficulty of cooling the machine, to which the author refers, in fact nullify this possible advantage?

Mr. Barnett goes on to deal with screw compressors, and I am surprised to find that what is a near relative of the screw compressor, the so-called 'Roots' or 'straight-load' machine, is not mentioned. There must be very many such machines in service, and I should have thought that by any reasonable definition they could be called positive rotary compressors. It is true that they have some notable disadvantages. The speed, for instance, is limited although it can be increased as has been done in the U.S.A. by special designs of timing gear. The maximum pressure ratio is small, although in fact not much smaller than the pressure ratios obtained with the rotating-drum type, according to the figures quoted on p. 317. The Roots type is a larger machine, duty for duty, than those described in the paper, but it is capable of development to large unit capacities, and if used well within its pressure range, i.e. for pressure ratios up to, say, 1·5, it is capable of fairly high efficiencies approximating to 80% on the adiabatic basis. It is also an oil-free machine, but in contradistinction to all the types described in the paper, it is a constant-volume machine, and perhaps the author felt that such a primitive device hardly warranted mention.

The screw compressor proper, sometimes termed the ' Lysholm compressor,' is a most interesting machine, ingenious in design and calling for high-class workmanship. My impression is that the air or gas flow is generally, if not inevitably, diagonally across the casing, so that a bottom inlet and a top outlet form the normal arrangement. This could, of course, be an embarrassment in some circumstances. The machine is inherently a balanced mechanism, rotationally speaking, but the necessity for expensive thrust-bearings and the high standard of mechanical design and production obviously required suggest a relatively high capital cost. A notable point about the design, as the author mentions, is the very high rotational speeds which the small rotor diameter makes possible and the extremely compact arrangement which may consequently be obtained. It would be interesting if the author could say what temperatures are obtained with this type of machine and also what might be the effect of dirty gas, for example, on the carbon glands.

Would Mr. Barnett say a little more about the non-metallic material used for the blades of the oil-flooded compressor and why it is used. A point is made in the paper that the oil loss is less than that occurring with a portable compressor of the piston type, but this does not necessarily mean that the amount of oil in the delivery

air is inherently less with this type of machine than with the piston compressor, and I suggest that, given oil separation equipment of equal efficiency, the piston-type machine may be no less satisfactory from this point of view. The philosophy behind this design, it seems to me, is quite different from that normally used; it is a kind of virtue-of-necessity approach which sometimes pays dividends.

No mention is made in the paper of the efficiencies and actual oil quantities. I wonder whether the oil quantity can be so large as seriously to affect the volumetric efficiency and power requirements of the machine. What is perhaps a more practical point is whether it is possible that the water vapour inhaled with the air, and the liquid water resulting from it, can cause difficulty with emulsification of the circulating oil. Perhaps the author is able to quote some typical efficiencies for this type of compressor.

Coming to the restraining-ring compressor, one point which strikes me when comparing Fig. 16 (the restraining-ring type) with Fig. 13 (the oil-flooded type) is the very large disparity in the number of blades, 18 in the one case and 8 in the other. Can the author give a reason for this? Is it primarily due to the fact mentioned on p. 324, that the use of 18 blades reduces the pressure difference across the blades and the air leakage? I notice also that the movement of the blades in their slots is not considered to be critical. I should like to know whether this is true in all cases or whether it could conceivably become a limiting factor, analogous to piston speed, for example, or is the tip speed itself always and inevitably the factor limiting the rotational speed? Finally, the complexity of this type of machine compared with the oil-flooded type presumably means greater cost.

Mr. **Barnett:** Mr. Andrews has drawn attention to one of the eight principal advantages I claimed for the rotary compressor, viz. rotary motion eliminates fatigue in working parts caused by alternating stresses. In a rotary-type compressor the stresses, although varying in intensity each revolution, are always in one direction. There is no question of any component being subjected to both tensile and compression stresses each revolution. When using the word 'alternating' I was really thinking of reversed stresses each revolution.

With regard to blade stresses, these are very safe and, in the case of an 18-blade restraining-ring machine, the blade stress is about 3000 lb/in². I know of no blade failures due to brittle rupture or fatigue. The few blade failures which have occurred have been mainly due to water getting into the machine. On one occasion in Scotland during the war, there was a severe frost and the main drain froze and the cooling water went back up the control-valve release pipes into the compressors. The operator started up the first machine and, having difficulty, went on to the next, and so on, and within a few minutes all three machines were badly damaged.

As described in the paper, the pressure difference across individual blades is quite low and, because of this, with the restraining-ring compressors there is no appreciable blade deformation.

The rolling-drum compressor does revolve at higher speeds than the restraining-ring type machine and this may be permissible because the blades are fully supported by the drum. The makers limit their design to 15 lb/in², and this tends to show that cooling problems and air losses through the drum do in fact nullify the advantage of the higher speed. The higher speed does, however, reduce the overall size of the machine and this, no doubt, is an additional advantage from the point of view of price.

Mr. Andrews refers to the relationship between the screw-type compressor and the Roots machine, and it is true to say that the screw type is a development based on the Roots principle. However, the screw-type is a compressor whereas the Roots-type is a blower and suitable for low-pressure work only.

With the screw-type compressor, controlled internal compression takes place, i.e. the trapped air is compressed before being released through the discharge port. In the case of the Roots blower, which is a constant-volume machine, the air is pushed through and most of the compression takes place in the discharge branch.

The paper discusses positive-type rotary *compressors* and, although the simple Roots-type is a positive machine and very useful within its range, it cannot, by any stretch of imagination, be termed a compressor.

Mr. Andrews refers to the lay-out of the screw-type machine and suggests that as the air flows diagonally across the casing this raises difficulties in the positioning of the branches. This is only the case in the larger machines where the bottom inlet and top outlet apply. In the case of the smaller units the rotors are arranged one over the other with the inlet and outlet branches on the sides of the casing.

The inclusion of expensive thrust bearings and the high standard of workmanship required does tend towards high first cost, but this is no doubt considerably compensated by the small dimensions of the machine due to its high speed. It should also be remembered that this machine delivers oil-free air which is a valuable feature for some applications. The air discharge temperatures obtained with these machines are considerably higher than with the other types of compressor discussed in the paper. This does not, however, present any mechanical difficulty nor is there an explosion risk because of the machine delivering air which has not been in contact with oil.

Mr. Andrews mentions the possible effect of dirty gas on the glands of the screw-type compressor which consist of a carbon pack not unlike the arrangement used on some steam turbines. I believe that they would probably have a longer life when in contact with gas or air free from gritty dirt.

Mr. Andrews refers to the oil-flooded compressor and asks why it has non-metallic blades. The answer is that it must have, because of the plain-bore cylinders. Experiments carried out years ago showed that if the restraining rings or rolling drum are eliminated, then one is compelled to use non-metallic blades to avoid rapid wear in the cylinder bore. These same experiments showed that compressors with plain-bore cylinders and non-metallic blades required considerably more power than the restraining-ring type with its high-tensile steel blades.

It is noticeable that the oil-flooded compressor has only eight blades in each stage, whereas the restraining-ring type has 18 and 24. The number of blades may have been cut to reduce the friction but the gain in power would be offset to some extent by increased air losses between cells.

I have no efficiency figures to quote, but the principle of the oil-flooded compressor does go some way towards isothermal compression because the oil cools the air as it is being compressed. I think, however, that as it has only eight blades and it runs very fast (high tip speed), and there is the big differential pressure across the blades, these factors may to some extent minimize the gain due to approaching isothermal compression. These, however, are my own views only. This is a new-type machine and the makers at this stage do not wish to quote efficiencies, but you may be interested in some rough calculations which I have made based on the few details available, such as the fact that the makers limit the air-temperature rise as it passes through the machine to 100° F over ambient.

On this basis I calculate that in the case of a 500-ft³/min compressor the amount of oil required to do the cooling is roughly 1000–1200 gal/h and the relatively small quantity of oil in the system has, therefore, to be pumped round many times each hour.

The oil-flooded compressor requires an oil-separating system and, as Mr. Andrews suggests, if the reciprocating compressor were also fitted with a separator it would be equally satisfactory from the point of view of oil loss.

The problem of oil separation with which the oil-flooded machine has to cope is considerable. If it is assumed that the preliminary separator is 99% efficient, with a 1000-ft³ compressor 20–24 gal/h of oil would be going forward to the final separator. This final separator would then have to be 99·85% efficient to ensure that oil leaving with the air did not exceed that from the 1000-ft³ restraining-ring type (without aftercooler and oil separator).

Mr. Andrews asks whether or not the oil quantity can be so large as to seriously affect the volumetric displacement. If my calculations are correct, the volume of oil is less than 1% of the free air delivered so that it does not materially affect the volumetric efficiency.

Theoretically it is possible to design the compressor so that the air is kept above the dewpoint on its way through the machine. For practical purposes, however, the oil has to be fed in at two or three points, and it is possible that some local over-cooling may take place. If it does then it is possible that emulsification of the oil could occur. On the other hand, if the machine runs too hot then the oil separation problem would be greater, so that it is probable that the temperature has to be controlled within fairly close limits.

I now refer to the questions in connection with the restraining-ring compressors.

By experience, the best combination of blades for first and second stages has been found to achieve minimum air losses between cells, and at the same time blade friction is minimized by the low side pressure on the blades themselves. Side wear on blades and slots does not occur and it is therefore true to say that the number of times the blades move in and out of the slots is not critical. There is, however, gradual wear on the tips of the blades and it is usually necessary to replace these after about five years' continuous running. In a large machine they will by then have worn down by about 4–5 mm, but the cylinder should still be within 0·001–0·002 in. of the original bore. The blades do not press heavily on the cylinder because of the restraining rings and the blade wears rather than the cylinder because it is thin in comparison to the circumference of the cylinder bore.

It is true to say that the blade tip speed of the restraining ring machine is the factor limiting the rotational speed of the machine.

With regard to Mr. Andrews' final point on relative costs of restraining-ring and oil-flooded compressors, the former is larger for a given output and no doubt more expensive to build but the latter has to bear the additional cost of the oil-circulating and separating apparatus, which will tend to minimize the difference.

Mr. **E. Townsend** (Hick, Hargreaves and Co., Ltd.): With regard to the size of the compressor, the practical engineer often wishes to install one which is greater than that required for his immediate needs. Mr. Barnett mentions two types of control, the electric stop–start control and the suction control. The electric stop–start is better where the machine is going to be stopped for considerable periods. Would it be any advantage, where the engineer has a machine which is larger than that required for his present needs, to have both methods of control fitted?

Secondly, when does it become advisable to have in a factory a long length of pipeline with compressors at a central station, and when would he recommend siting separate compressors near the places where they are required? Can he give some idea of the air velocities in the pipe to which it is common to work, as a guide to the practical engineer? Can he give an idea of the cost of the variable-speed type of control as compared with the suction-valve control? Variable speed would seem to most engineers to be very attractive.

The author mentions that with the restraining-ring type of compressor, up to about 40% of the lubricating oil is recovered at the intercoolers. Is it his suggestion that this can be used again in the lubricator of the machine, or that it can be used for other services, but not necessarily for the actual compressor?

Mr. **Barnett:** The size of the compressor in relation to present factory requirements is influenced by size of factory and the air pressure required. If, for example, a factory has a present load of 500 ft³/min and an eventual load of say 1000 ft³/min, then in these circumstances I do not think it would pay to install the large machine in the first instance. The light load losses would be high with the automatic suction-type control and electrical stop–start gear would almost certainly be required.

To compare automatic stop–start control with the normal automatic suction control, the former is often fitted to compressors in factories where the night load is much lighter than the day load. The stop–start control is used at night when the demand for air is usually intermittent, whereas during the day, when the machine may be almost fully loaded, it pays to use the automatic suction control so that quite often both are fitted in order to get the best of both worlds.

Concerning central compressor house *v.* individually sited machines, almost all new factories employ the former in conjunction with adequate air mains usually in the form of a ring main with air velocities not exceeding 40 ft/s. The main advantage is saving in manpower because, although rotary compressors are suitable for running unattended, most firms seem to prefer to employ an attendant and with this central compressor house one man can look after all the machines. Another advantage is that the number of machines running to suit the load at a particular time can more readily be controlled.

In almost all cases where compressors are dispersed about the factory it has been done to overcome excessive pressure losses caused by air mains becoming inadequate as the load has grown with the factory.

It is not possible for me to quote comparative costs of variable speed and auto-suction control, but the capital cost of the latter is certainly lower. I can appreciate that the idea of using a variable-speed drive is attractive to most engineers, but my experience has shown that in the great majority of cases it is eventually rejected because of its high initial cost.

The oil drained from the intercooler should not be used again in the compressor. It is to some extent slightly emulsified and contains some of the dirt which might have passed the air filter.

Mr. **W. Scott** (James Howden and Co., Ltd.): One difficulty which was experienced with the very early versions of the two-stage screw compressor, and which has since been overcome, leads to the question of whether or not with the restraining-ring or rolling-drum compressor of the two-stage type any difficulty is experienced due to the carry-over of condensed water causing corrosion in the high-pressure stage.

Another question which may be of interest to steel manufacturers is that of wear due to dirt with air in those machines in which there is some rubbing contact between

the blades and casing. Is the filter efficiency sufficiently good to eliminate harmful dirt, or are there any special steps which should be taken in dirty conditions?

Mr. **Barnett**: Corrosion in the high-pressure stage can undoubtedly occur if the compressor is incorrectly run. The method usually recommended with a two-stage restraining-ring compressor is to run with the intercooler as cold as possible so as to remove the maximum amount of water from the air and then to run the second stage on the warm side. If the second-stage jackets are hotter than the air from the intercooler then condensation cannot take place.

I have referred in the paper to a new oil containing an additive which is an anti-wetting agent and this puts a protective coating on to the metal and keeps the water off the surfaces. This is an additional safeguard which will prevent corrosion even if the machine is run incorrectly. It must not be thought, however, that even if this corrosion does occur, it is necessarily serious. What happens is that the high-pressure rotor gets a rusty mark opposite the air inlet port and that is about all. I suppose that in a particularly bad case, water vapour could eventually cause pitting of the roller bearings.

Regarding air filtration and the effect of dirt on blade-type machines, I have seen machines working in steelworks under the most appalling conditions. In one instance a machine was neglected so badly that the ferrule-type filter became almost blocked and the element was blown out of the filter casing by the slight blowback of air when the machine tripped out. On three separate occasions I found this filter (which was situated outside the compressor house) on the ground. In spite of such treatment the machine ran continuously for three years before requiring an overhaul.

In another case a machine was installed in the centre of a particularly dusty foundry running night and day. To allow frequent cleaning of the filter without shutting down, three oil-bath filters were arranged on a manifold, each with its own isolating damper. Two filters were designed to deal with the input of air and each filter was cleaned every three days.

When applying blade-type compressors to coal gas it is advisable to fit a suction filter to deal with any scale which might leave the piping. The Gas Board has its own standard filters which are quite adequate for this purpose. The blade-type compressors are suitable for dealing with the refined gas as it leaves the gasworks, but they are not suitable for dealing with unpurified gas as it leaves the retorts.

Mr. **J. Roy** (Cowans, Sheldon and Co., Ltd.): For a number of years I was associated with the screw rotary compressor to which the author refers. Recalling my experiences with that machine, filtering is one point which cannot be over-emphasized. Reference has already been made to this, yet many buyers of complete compressor installations are told that a filter will cost several hundred pounds. They decide to make do with a simple gauze screen, but this may prove an expensive economy. Siting the filter where it can inhale the cleanest possible air rather than somewhere near the machine is also of great importance.

With the screw rotary compressor it is advisable to fit the best possible filter, but many installations have run for quite a considerable time with relatively poor filtering without ill-effects. I believe that in some European countries, particularly Germany, where these machines have been used for a considerable period in steelworks and gasworks, it has been found that when the rotors become built-up with greasy products, efficiency is improved by the reduction of the clearances resulting from a build-up of dirt and grease on the rotors.

Finally, it is worth noting that an oil-free compressor such as the Lysholm type is not troubled by the passage through it of any dirt not trapped by the filter and all such dirt will be passed on to the process. Thus any shortcomings in the filter will be detrimental to the process rather than to the compressor plant.

Mr. **Barnett**: In my experience I have always found that the customer has accepted the filter recommended by the compressor maker. A gauze screen cannot be classed as a filter, as it will keep out foreign bodies but not the fine dust held by a normal air filter. A filter costing several hundred pounds would be for quite a large unit. The cost of a filter for a 2000-ft^3/min compressor would not exceed £100.

I should have thought that gritty material would adhere to the greasy build-up referred to by Mr. Roy and that this would form a grinding paste and cause abrasion.

Mr. **T. Nuttall** (Hick, Hargreaves and Co., Ltd.): In buying a rotary compressor, or a compressor of any kind, how would one compare the relative efficiencies of the different makes and check the figures given in the makers' tenders? In buying a compressor and comparing it with a machine tool, what would be the down-time per annum and what would be the capital cost per cubic foot of air at, say, 100 lb/in^2 pressure?

Mr. **Barnett**: In the industry we know that it is necessary to compare different types of compressors on a common basis to allow a fair comparison of first cost and running cost. Anyone buying an air compressor should state on his enquiry that the machine must be tested in accordance with B.S. 726. This lays down very definite methods of testing using low-pressure nozzle tests. In the case of a reciprocating compressor it is necessary to have an air receiver followed by a valve to maintain the working pressure and the air is afterwards expanded down to atmospheric pressure before passing through the standard nozzle. The differential pressure across the nozzle, together with the barometric pressure and the air temperature, are recorded and with the help of the formula it is then possible to calculate the free air delivered, referred to a 30-in. barometer and 60° F ambient air temperature.

The drive is another important point. If test equipment is to be used, then it is advisable to insist on a calibrated d.c. motor, or in the case of a.c. equipment the power readings should be recorded by the two-wattmeter method. This latter method cancels out the wide variations which can be introduced owing to power factor. With the above as a basis, and performance data guaranteed within a testing tolerance of $\pm$ 5%, the purchaser will be adequately covered. Some claims made, particularly in connection with high-pressure single-stage compressors, are a little optimistic.

I take it that by 'down-time', Mr. Nuttall means the average time which a machine has to be out of commission each year for servicing. I think that the rolling drum, screw, and restraining-ring types would run for very long periods without dismantling. I have no information about the servicing of the oil-flooded compressor because it is a relatively new type, but with regard to the other three, one week in each year should be more than enough, assuming that the machines are running continuously.

The capital cost per cubic foot of air at 100 lb/in^2 varies considerably with the size of the machine, and between the different types of compressor. For this reason it is impossible to generalize, and I should prefer not to give a figure which might prove very misleading.

Mr. **A. Stark** (Steel, Peech and Tozer): I approach this subject from the steelworks maintenance point of view.

In common with most other works, we are finding that with increasing automation, larger demands for compressed air are being made. This is becoming so important

that we must seriously consider running costs, and in a large works these can be an expensive item. For our purposes, a common bus main from one end of the works to the other is necessary to meet all requirements of high-pressure users. For chippers and pneumatic chisels, etc., it is necessary to have a minimum of 80 lb/in², and preferably nearer 100 lb/in² at the machines, but in practice there is a tendency to tap off the main to blow fires, cool instruments, and sometimes to dry ladles, so that the mains pressure quickly drops and every user in the works suffers.

We have been seriously considering whether, in addition to the large high-pressure main, it would be advisable to provide an independent low-pressure main for these subsidiary uses. Can the author suggest a low-pressure main which would be economical for such uses?

There are one or two questions which I should like to ask concerning the particular machine that Mr. Barnett has described. Is this a machine which is considered by the people who use it (excluding the author!) to be better than the conventional reciprocating machine? With the high-pressure reciprocating machine, the costs are comparatively high for down-time and attendant labour. Down-time is chiefly due to carbonizing at the valves, cleaning after- and intercoolers, etc. It is not always possible to put all the machines in one building, and when a machine has to be sited a long way from a central station the same attendants cannot be used.

Would a machine of the type under discussion run consistently well without an attendant? Can one of these machines be run simply with an occasional visit by a man to fill an oil bottle or a grease lubricator? Is the author's machine better than the conventional type, where there is the possibility of a connecting-rod failure, or of hot bearings, etc.? If it is possible to leave the machine almost unattended, it will appreciably cut down the costs. I know of a case where it costs £1800 a year simply for attendants' wages to look after one machine.

In the steelworks, if a portable compressor is wanted for isolated work, we usually require to have attendants present for 24 hours a day. Is that necessary with the type of machine described by the author?

We have been told that the down-time is about one week a year. Can the author compare the reliability of this machine with that of conventional machines? Down-time, spares, attendance, etc., are all part of maintenance costs. We should like to know how all these items compare in the case of the author's machine and a reciprocating compressor.

We have had trouble with air filters, for we find that the sieve type of filter quickly chokes and can be a nuisance, because unless it is attended to frequently, it can sometimes be more trouble than no filter at all.

In our experience, the oil-wash type of filter, though not perfect, is the best available. It works freely under all conditions, whereas with the sieve type there is a gradual restriction of the filtering area from the time it is put to work.

Mr. **Barnett**: Mr. Stark has made some very good points on behalf of the steel industry. Theoretically the low-pressure main is well worth while, but I happen to have visited the steelworks with which Mr. Stark is associated, and I should want to weigh up the matter carefully before giving an answer, because it would mean miles of piping, and the difficulty with a low-pressure system is that large pipes are necessary if the pressure losses are not to be a very large proportion of the pressure generated at the compressor. In principle, however, I would say that if there is a 100-lb/in² system in a works and air is wanted for another purpose at 20–30 lb/in² it will pay to have two systems, with allowance for the length of the air mains required. There is an obvious saving in power, the amount being about 50%.

On the question of maintenance of reciprocating as compared with rotary machines, the major selling point of the rotary machine is minimum maintenance, which makes possible the long runs we believe that no other type of compressor can give. It is common for a machine to run three or four years without being touched except for cleaning the air filters. If a comparison is made of the power consumption of a given type of two-stage rotary compressor and that of an equivalent reciprocating compressor, then on the test bed the good reciprocating type will be more efficient, but on the job they are much the same, the reason being the point which Mr. Stark has made about the valves. The compressor valves at Mr. Stark's works are cleaned at regular intervals. I do not know whether he is familiar with the losses that take place in a reciprocating compressor when the valves are in a bad state, for they are very considerable and the cost of cleaning the valves is negligible in comparison with the loss of efficiency as the valves progressively deteriorate. When in a bad state, the valves slip air back and the machine loses volumetric efficiency. If the output of a reciprocator is plotted, the test-bed efficiency is usually obtained after the valves have been attended to and then the output gradually deteriorates until the next valve overhaul. If an average is taken of the saw-edged curve, then the line is very similar to that of the output curve for a rotary machine of comparable size. The rotary machine maintains its output for very long periods, maintenance costs are lower, and hence we believe that it is a better proposition.

Rotary compressors can certainly be left unattended. An installation delivering 1000 ft³ at 100 lb/in² can safely be left between the filling of the lubricators, say every eight hours. One filling will last for twelve hours, but eight hours is wiser. I must qualify this by saying that some safeguards are desirable. I should want an automatic device to shut down the machine if the water failed, and some control by air temperature or water outlet temperature which would come into action if something else went wrong. With that proviso, rotary compressors can be left unattended. I know of a pumping station where the lubrication was arranged so that the machine could be left for a fortnight because it was so remotely situated.

With regard to reliability, there are some extremely reliable reciprocators, apart from the valves, but rotary compressors are equally reliable and have no valves requiring frequent attention, so that the maintenance costs are less. Both machines, however, have their parts to play, and on the higher pressures the reciprocator does a good job.

Regarding air filters, I agree that the oil-bath filter is very efficient. It cleans itself and because of this can be left for long periods without servicing.

Mr. **Stark**: Am I right in saying that in a steelworks where there is an old compressor with three attendants, if we put in its place one of the machines described by Mr. Barnett, with the various devices he has mentioned, the attendants could be dispensed with?

Mr. **Barnett**: Certainly, but you will have to cope with the attendants!

Mr. **J. H. Ashton** (The Steel Company of Wales Ltd.): I am in charge of the air compressors at the Abbey, Margam, and Port Talbot works. The compressor houses are widely separated, and one of the problems has been the provision of attendants.

When the Abbey works were planned the consultants decided on two houses connected by a ring main, one containing four machines and the other three, all

reciprocators of 1275-ft³/min capacity. It has now been decided to instal a 600-ft³/min rotary machine of the oil-immersed type at Port Talbot works to meet the demands of six 100-ton O.H. steel furnaces.

There is one factor in the comparison between rotary and reciprocating compressors which has not been mentioned so far. I refer to the heavily piled foundation required for the reciprocators. At the Abbey works Franki piles were used to support a concrete raft and these were driven to an average depth of 40 ft; nevertheless the houses vibrate considerably and transmit this vibration to adjoining structures, causing windows and corrugated sheeting to rattle, and annoyance to those using telephones. The new rotary compressor, on the other hand, was almost vibrationless on test, thus enabling us to dispense with piled foundations; furthermore, because of its compactness, the building will be smaller, thus greatly reducing the capital cost. It is hoped to run this machine unattended except for the occasional visit of a fitter to make adjustments, check temperatures, etc.

For future developments at Abbey works, there is sufficient room in the larger of the two compressor houses to accommodate a battery of, say, four 600-ft³/min rotaries without strengthening the foundations. The existing overhead crane and cooling-water main would serve this purpose.

Mr. **Barnett**: The point about foundations is very interesting. I think that all types of rotary compressor can be run on a floor with very little bolting down, provided the floor will support the weight of the machine without sinking, and if the plinth is strong enough there is no need for a foundation.

As an example, large rotary compressors are used in coal mines where they are placed on a three-point support, two at one end of the bedplate and one at the other, without bolting down. This allows for movement of the floor, and enables the machine to be moved easily to a new site when required.

CORRESPONDENCE

Sir **Henry Clay** (McLellan and Partners) wrote: I was most interested in Mr. Barnett's statement that the lowest maintenance is on compressors with start–stop rather than unloader control. This has also been my experience, but many maintenance engineers do not agree. Of course, lower compressor maintenance is to some extent offset by the higher maintenance of the starting gear.

There is an interesting relationship between compressor size, receiver capacity, and load size, and the resultant number of starts and stops. The maximum number of starts per hour which occur when the load is half that of the compressor capacity, is roughly given by the formula:

$$\frac{220 \times \text{compressor capacity (ft}^3\text{/min of free air)}}{\text{pressure differential (lb/in}^2\text{)} \times \text{storage capacity (ft}^3\text{)}}$$

It should be noted that the compressor capacity is that actually in service, and the storage capacity should include that of the pipes, etc., as well as the receivers.

Mr. **Barnett** wrote in reply: Experience has shown that with rotary compressors maintenance costs are slightly lower when employing the start–stop control.

When using the auto-suction control, the temperature variations are wider because the machine runs under vacuum when unloaded which probably accounts for the difference.

The Future Engineering Development of the Gas-cooled Nuclear Reactor

As part of the Autumn General Meeting, 1957, the Institute has arranged an Evening Lecture, to be given at the Royal Institution, Albemarle Street, London W.1, at 6.0 p.m. on 24th September. The lecturer will be Professor J. M. Kay, who occupies the Chair of Nuclear Power at the Imperial College of Science and Technology. He has chosen as his subject "*The Future Engineering Development of the Gas-cooled Reactor.*"

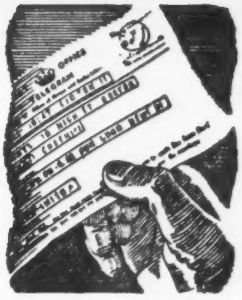
Professor Kay, who was educated at Sherborne School and Trinity Hall, Cambridge, began his engineering career as an apprentice in the Locomotive Works at Crewe. After service in the R.N.V.R. during the war, he returned in 1946 to the Engineering Department at Cambridge University, where he carried out research on fluid mechanics with Sir Melvill Jones. In 1948 he joined the staff of the newly formed Department of Chemical Engineering, where he lectured in fluid mechanics and heat and mass transfer. He was appointed Chief Technical Engineer in the Department of Atomic Energy Production (subsequently the United Kingdom Atomic Energy Authority, Industrial Group) at Risley in 1952. Professor Kay was appointed to the Chair of Nuclear Power at Imperial College in October, 1956.

The Lecture on 24th September will be divided into two parts. The first part will consist of a review of existing reactor technology, under the headings of fuel elements (nuclear, metallurgical, mechanical, and thermal requirements; fuel element support; charge and discharge), core design (general arrangement and structure of reactor core; engineering and metallurgical problems of the pressure vessel), and gas circuit (design of gas ducting; heat exchangers; gas circulators and method of drive). The second part of the lecture will be devoted to the future development of the gas-cooled reactor: the range of development using the existing basic fuel technology derived from the Calder Hall design; the limitations set by canning material, the properties of uranium, thermal stresses, and distortion of fuel elements; the possible use and implications of alternative canning materials; alternative forms of fuel; the choice of coolant gas; progress in pressure vessel design. The lecture will end with a summary of the future prospects for the gas-cooled reactor.

Admission to the Lecture is by ticket only; tickets are available, free of charge, from the Secretary.

N E W S

Announcements and News of Science and Industry



THE IRON AND STEEL INSTITUTE

Autumn General Meeting, 1957

The Autumn General Meeting of the Institute is being held in London on **24th September, 1957.** The detailed programme is as follows:

Morning Session (at 4 Grosvenor Gardens, London S.W.1)

10.45–11.0 A.M.—Formal business and election of Members.

11.0 a.m.–12.45 p.m.—Presentation and joint discussion of the following papers:

"The Influence of Slag Properties on Pig-iron Composition," *by A. J. Burgess and B. G. Baldwin* (June, 1957).

"The Liquidus and High-temperature Properties of Blast-furnace Slags," *by B. G. Baldwin* (August, 1957). (A short film will be shown).

Afternoon Session (at 4 Grosvenor Gardens, London S.W.1)

Session A (in the Library on the Ground Floor).

2.45–5.0 p.m.—Presentation and discussion of the paper:

"High-boron Alloy Steels," *by T. H. Middleham, J. R. Rait, and E. W. Colbeck* (September, 1957).

Session B (in the Meeting Room on the First Floor).

2.45–5.0 p.m.—Presentation and discussion of the paper:

"Proposal for a Self-lining Blast-furnace," *by W. A. Archibald, T. P. Brown, and L. A. Leonard* (September, 1957). (A short film will be shown)

Evening Lecture at the Royal Institution, Albemarle Street, London W.1

5.15–6.0 p.m.—Tea at the Royal Institution.

6.0 p.m.—Lecture on "The Future Engineering Development of the Gas-cooled Nuclear Reactor," by Professor J. M. Kay (*see* p. 54).

Buses will be available at 4 Grosvenor Gardens after the Afternoon Sessions to take Members to the Royal Institution. Members of the Institutions and Societies comprising the British Nuclear Energy Conference will be welcome at Afternoon Session *A* and at the Lecture. Admission to the Lecture is by ticket only; tickets are available, free of charge, on application to the Secretary.

The Autumn Meeting is followed on 25th and 26th September by the Iron and Steel Engineers Group Meeting on "Air Pollution in the Iron and Steel Industry," details of which are given below. Those attending this Meeting are welcome to all the Sessions on 23rd September, and especially to the Lecture.

Joint Meeting in Sheffield

A joint meeting of The Iron and Steel Institute, the Sheffield Metallurgical Association, and the Sheffield Society of Engineers and Metallurgists is being held at Sheffield University on Thursday, **28th November,** at 2.15 p.m. The following papers are being presented and discussed (the dates in parentheses refer to publication in the *Journal*): "Heat Flow in Ingot Hot-tops," *by G. Fenton* (August, 1957) and "Studies on Ingot Feeder Heads," *by H. S. Marr, G. Fenton, and W. H. Glaisher* (October, 1957); "The Low-temperature Impact Properties of Cast Steel," *by W. J. Jackson and G. M. Michie* (October, 1957); "High-boron Alloy Steels," *by T. H. Middleham, J. R. Rait, and E. W. Colbeck.*

Co-operative Translation Service

Since the new Translation Service was started in May, 1957, 17 translations have been prepared and 81 are in hand. The numbering of the translations in the new service continues from the last number (531) in the earlier service. The translations now available are:

532. POPOVA and ZASLAVSKAYA: "Determination of Free and Carbide Carbon in Austenitic Cr–Ni Steel." *Zavodskaya Laboratoriya*, 1955, vol. 21, No. 11, pp. 1285–1288. (£2 0*s.* 0*d.*)

541. BREGMANN: "Economic Evaluation of Steelmaking Processes." (Abridged). *Stal*, 1957, No. 3, p. 268. (£2 0*s.* 0*d.*).

548. CHERNOKH: "Construction of Blast-furnaces with Thin-walled Stacks." *Stal*, 1956, No. 8, pp. 682–689. (£1 9*s.* 0*d.*)

549. GUBAREV: "New Design of High-Stability Hot-blast Valve." *Stal*, 1955, No. 11, pp. 1037–1038. (£1 1*s.* 0*d.*).

550. GLADUNOV: "Changing Charging Gear of Blast-furnaces at the Novo Tagil Plant in Russia in Two Days." *Stal*, 1956, No. 12, p. 1134. (£1 0*s.* 0*d.*).

551. KULIK and others: "The Use of High-Alumina Bricks in Hot-blast Stoves." *Stal*, 1956, No. 7, p. 582. (£1 0*s.* 0*d.*).

552. GRUBERMAN: "Russian Experience in the Automatic Control of Wheel Plant Furnaces." *Stal*, 1956, No. 12, p. 1103. (£2 1*s.* 0*d.*).

562. DILLI: "Measures for Speeding-up Internal Wagon Circulation on Steelworks Wide Gauge Rail Networks." *Stahl u. Eisen*, 1957, Apr. 18th, pp. 487–491. (£1 10*s.* 0*d.*). Free to B.I.S.R.A. Members.

563. BRILL: "Construction of Railway Wagons for Bulk Transport and Special Uses in Iron Works." *Stahl u. Eisen*, 1957, Apr. 18th, pp. 469–476. (£5 0*s.* 0*d.*). Free to B.I.S.R.A. Members.

564. BELLET: "The Possibilities of Accelerating the Turn-round of Company-owned Wagons in a Metallurgical Plant." *Stahl u. Eisen*, 1957, Apr. 18th, pp. 496–503. (£4 10*s.* 0*d.*) Free to B.I.S.R.A. Members.

565. MOREL: "Building and Operation of Coal, Coke and Ore Wagons." *Stahl u. Eisen*, 1957, Apr. 18th, pp. 483–486. (£2 5*s.* 0*d.*). Free to B.I.S.R.A. Members.

569. GUENOT: "Various Examples of Application of Statistical Methods. (Analysis of Carbon—Experiments on Shock Resistance—Comparison of Methods of Steel Manufacture)." Institut de Statistique de l'Université de Paris, Journées de la Sidérurgie, 1954, June 22nd, 13–17. (£1 10*s.* 0*d.*).

576. STROHMEIER and RICHTER: "Applications of Mathematical Statistics in Iron and Steel Works." *Stahl u. Eisen*, 1955, vol. 75, Nov. 3rd, pp. 1494–1501. (£4 0*s.* 0*d.*).

580. PÖHNER: "The Movement of Ore to the Blast-furnace." *Stahl u. Eisen*, 1957, preprint. (£3 15*s.* 0*d.*). Free to B.I.S.R.A. Members.

581. BERNARD-MICHEL: "Transport of Iron Ores." *Stahl u. Eisen*, 1957, preprint. (£2 0*s.* 0*d.*). Free to B.I.S.R.A. Members.

621. BRAND: "Apparatus for Measuring the Depth of Cracks." *Stahl u. Eisen*, 1957, vol. 77, May 2nd, No. 9, pp. 576–581. (£2 15*s.* 0*d.*).

630. SCHENCK *et al.*: "New Process for Sampling of Killed and Rimming Steel for the Determination of Oxygen and Hydrogen." *Arch. Eisenhüttenwesen*, 1957, vol. 28, Mar. pp. 123–125. (£1 0*s.* 0*d.*).

Note: When two copies are required, there will be 50% reduction for the second copy. Six copies can be bought for the price of two, and twelve copies for the price of three.

NEWS OF MEMBERS

Mr. **W. H. Adams** is now Project General Manager for Head Wrightson Iron and Steel Works Engineering Ltd. in India.

Dr. **H. T. Angus** has been appointed Assistant Director of the British Cast Iron Research Association.

Dr. **B. G. Baldwin** has left the B.I.S.R.A. Blast Furnace Laboratory at Imperial College to join the Steel Company of Wales Ltd. as a Research Metallurgist.

Dr. **Marian Balicki** has assumed full-time duties as an engineering specialist in the Department of Physical Metallurgy and Ceramics at the Sylvania-Corning Nuclear Corporation, Bayside, N.Y., U.S.A.

Mr. **C. J. Barfield** has left the A.P.V. Co., Ltd., Crawley, to become a Development Engineer with the English Electric Co., Ltd., Stevenage.

Mr. **J. W. Barton** has obtained the degree of M.Eng. at Liverpool University, and is joining the Department of Mining and Metallurgy, University of Alberta, Edmonton, Canada, as a Research Assistant.

Mr. **H. Bates** has left the Ironmaking Division of B.I.S.R.A. to join Huntingdon, Heberlein and Co., Ltd.

Mr. **A. J. Blanchard** has left B.I.S.R.A. to join Huntingdon, Heberlein and Co., Ltd.

Mr. **J. T. Brookes** has retired from the position of Melting Shops Superintendent of Steel, Peech and Tozer, Sheffield, after 50 years' service.

Mr. **Arnold Carr** has been elected President of the Refractories Association of Great Britain.

Mr. **A. Conway** has left B.I.S.R.A. Plant Engineering Division to join Morgan Brothers (Publishers) Ltd., on the staff of "*The Engineer*."

Mr. **D. L. Davies** has been appointed Chief Engineer to the London Hospital.

Mr. **G. S. Dearnley** is now with the Coal Research Establishment of the National Coal Board, Stoke Orchard, near Cheltenham.

Mr. **V. Delport** has received a "Service Citation" award from the American Foundrymen's Society in recognition of his distinguished service to the Society as its European representative.

Dr. **J. V. Harding** has left the International Meehanite Metal Co., Ltd., to join British Oxygen Research and Development Ltd.

Mr. **G. H. Jackson** has joined the National Association of Drop Forgers and Stampers as a Technical Officer.

Mr. **J. H. Jolly** has retired from the Board of John Lysaght Ltd.

Mr. **B. K. Kaplish** has been awarded the degree of M. Met. of Sheffield University.

Mr. **J. F. Lancaster** has left the A.P.V. Co., Ltd., to join the Kellogg International Corporation.

The Hon. **R. G. Lyttelton** has been appointed a Director of Guest Keen and Nettlefolds (Cwmbran) Ltd.

Mr. **E. B. May** has been appointed Electrical Engineer for the Ontario Ministry of Mines at Blind River.

Mr. **H. Morrogh** has been appointed Deputy Director of the British Cast Iron Research Association.

Mr. **J. B. Moss** is now Lecturer in Metallurgy at North Lindsey Technical College, Scunthorpe.

Mr. **R. L. Richards** has been appointed Manager of the newly formed Federation of Rhodesia and Nyasaland Standards Association.

Mr. **G. W. Stewart** has left Rotax Ltd. to join the Cummins Engine Co., Ltd.

Mr. **T. R. Twigger** has been awarded the Oliver Stubbs Medal of the Institute of British Foundrymen for 1957.

Mr. **V. Watkins** has been appointed a Director of Steel, Peech and Tozer.

Mr. **R. Whittaker** has joined the Electric Furnace Co., Ltd.

Mr. **C. H. Wilson** has been nominated as Junior Vice-President of the Institute of British Foundrymen for 1957–1958.

Obituary

Mr. **Leonard Reeves Broome** (*elected* 1935), of London, on 15th June, 1957.

Mr. **Roy Henry Davis** (*elected* 1947), of Fonthill, Ont., Canada.

Mr. **Williams Evers** (*elected* 1949), of Liverpool.

Mr. **Robert Charles Good** (*elected* 1937), of Pittsburgh, Pa., U.S.A., on 11th January, 1957.

Mr. **Heinrich Kriegsheim** (*elected* 1926), of New York, N.Y., U.S.A., on 22nd April, 1957.

Mr. **Haakon Styri** (*elected* 1920), of Philadelphia, Pa. U.S.A., on 13th September, 1955.

Mr. **Alfred John Wesson** (*elected* 1925), of Wednesbury on 9th July, 1957.

CONTRIBUTORS TO THE JOURNAL

W. A. Archibald, B.SC., PH.D., F.INST.CERAM.—Head of the Slags and Refractories Section, Chemistry Department, British Iron and Steel Research Association.

W. A. Archibald

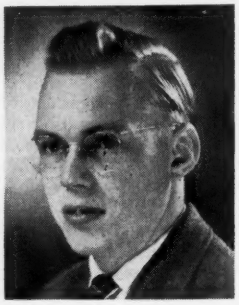
Dr. Archibald was educated at Dumbarton Academy, Glasgow University, and the Royal Technical College, Glasgow, specializing in physical chemistry. Before joining B.I.S.R.A., he was Technical Manager for the Scottish Group of General Refractories Ltd. He is a Founder Fellow of the Institute of Ceramics and a Member of Council of the British Ceramic Society.

T. P. Brown—Research Assistant, Slags and Refractories Section, Chemistry Department, British Iron and Steel Research Association.

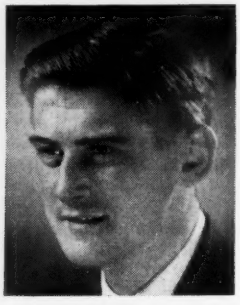
Mr. Brown was educated at Bancroft's School and the South West Essex Technical College, where he is now studying part-time for the A.R.I.C. examination. In 1951 he joined the National Coal Board in South Wales and gained experience in a washery control laboratory. He took up his present appointment two years later.

L. A. Leonard, B.SC.—Senior Scientific Officer, Slags and Refractories Section, Chemistry Department, British Iron and Steel Research Association.

Mr. Leonard was educated at Holloway School, and at University College, London, graduating with Honours in Chemistry in 1951. On leaving college he took an appointment with the North Thames Gas Board, work-



T. P. Brown



L. A. Leonard

J. R. Rait

D. R. Thorneycroft

ing in their Research Laboratories for four years on problems connected with refractories for gas making. He took up his present appointment in 1956.

J. R. Rait, D.SC., PH.D., A.R.T.C., F.I.M.—Research Controller and Local Director, Hadfields Ltd., and Director of Hadfields Forgings Ltd., and of Hadfields Steels Ltd.

Dr. Rait received his early training at Glasgow University, where he graduated in 1934 with a First-Class Honours B.Sc. Degree in Physical Chemistry (Pure Science). He then studied metallurgy at the Royal Technical College, Glasgow, and carried out research on the constitution and viscosity of silicate slags, designing a viscometer for operation at temperatures up to 1700° C, for which he was awarded his Ph.D. and A.R.T.C. in 1938; he was also appointed Ferguson Fellow in Applied Science. His D.Sc. degree was awarded for original investigations on a variety of problems allied to steelmaking, including basic refractories, basic slags, non-metallic inclusions in steel, etc.

After two years with the British Ceramic Research Association, where he carried out research on refractories, he entered the steel industry; after experience in the Research Department of William Jessop and Sons Ltd., Sheffield, Dr. Rait became Technical Manager in charge of the melting departments, a position which he held for a number of years. He is the author of a book on "Basic Refractories," published in 1951, and of numerous papers dealing with research on refractories and metallurgical problems. He is a Fellow of the Institution of Metallurgists and of the Institute of Ceramics, and a member of several other leading technical societies.

D. R. Thorneycroft, B.SC., A.I.M., A.C.T. (BIRMINGHAM)—Section Head, Welding and Non-ferrous Department, The Mond Nickel Co., Ltd.

Mr. Thorneycroft was born at Birmingham in 1921 and educated at the Central Grammar School. He joined the Mond Nickel Co., Ltd., in 1939 as an assistant in the Birmingham Laboratory, and during the war studied engineering and metallurgy at the Birmingham College of Technology. He was awarded the External Honours Degree in Metallurgy of the University of London in 1944 and was appointed to the senior research staff in the same year. During the next five years he gained research experience in several fields, including that of powder metallurgy. From 1949 to 1953 he investigated the transformation characteristics of cast and wrought alloy steels. He has since then been engaged on research in the ferrous and non-ferrous field of welding metallurgy. He took up his present appointment in 1956.

IRON AND STEEL ENGINEERS GROUP

Meeting on Air Pollution

A two-day meeting on "*Air Pollution in the Iron and Steel Industry*" is being held by the Engineers' Group at Church House, Westminster, London, S.W.1, on Wednesday and Thursday, **25th and 26th September, 1957.** The programme is as follows:

Wednesday, 25th September

9.30–10.0 A.M.—Welcome by Mr. A. H. Ingen-Housz, President of The Iron and Steel Institute. Opening remarks by Mr. W. M. Larke, Chairman of the Engineers' Group.

10.0 A.M.–12 NOON—Presentation and joint discussion of the following papers:

"External Pollution from an Iron and Steelworks and Measures towards its Reduction," *by S. H. Brooks and W. J. Calvert.*

"External Dust Deposition and Sulphur Emission," *by H. G. Jones and J. T. Davies.*

"The Capital Costs of Some Waste-gas Cleaning Plants for Use in Iron and Steelworks," *by R. A. Granville.*

12 NOON–1.15 P.M.—Presentation and discussion of the paper:

"Mitigation of Air Pollution on Sinter Plants," *by A. H. Meadley, J. G. Colvin, and H. J. Camble.*

1.15–2.30 P.M.—Buffet luncheon (tickets 9*s.* each).

2.30–5.0 P.M.—Presentation and joint discussion of the following papers:

"Mitigation of Smoke, Dust, and Grit at Coke-oven Plants," *by G. W. Lee and J. P. Graham.*

"The Extraction of Sulphur from Coke-oven Gas and the Manufacture of Sulphuric Acid," *by P. R. Purcell and T. H. Williams.*

7.30 P.M.–10 P.M.—Buffet supper in the Napoleon Suite at the Café Royal, Regent Street, London, W.1. (Tickets one guinea each).

Thursday, 26th September

10.0 A.M.–12.45 P.M.—Presentation and joint discussion of the following papers:

"The Operation of Electrostatic Precipitators on Open-hearth Furnaces at Fairless Works," *by E. B. Speer.*

"A Pilot Plant for the Removal of Iron-oxide Dust from the Fumes arising in the Pre-refining of Iron with Oxygen," *by L. Septier.*

"Waste-gas Cleaning Systems at Oxygen Steel Plants," *by A. Vacek and A. Schertler.*

"Gas Cleaning in Relation to Oxygen Pre-Refining and the Rotor Process at Oberhausen," *by A. Behrendt.*

12.45–2.0 P.M.—Buffet luncheon (tickets 9*s.* each).

2.0–3.15 P.M.—Presentation and joint discussion of the following papers:

"Dynamic Dust and Fume Precipitators," *by F. Wright.*

"Cleaning of Fume from Arc Furnaces," *by A. S. Hipkin.*

3.15–5.15 P.M.—Presentation and joint discussion of the following papers:

"Measurement of Dust in Flue Gases," *by R. Granville and R. Jackson.*

"The Complete Elimination of Dust from Gases at 300–400° C," *by H. L. Riley.*

"The Fulham–Simon-Carves Process for the Recovery of Sulphur from Flue Gases," *by T. Kennaway.*

6.30–9.30 P.M.—Special excursion on the River Thames on board m.v. *Queen Elizabeth*; dinner will be served on board (tickets £2 5*s.* 0*d.*).

Preprints of all the papers to be presented will be available before the Meeting, and a bound volume of Proceedings will be published during 1958. The Proceedings will also include a report of the proceedings at

the Meeting on "Water Pollution in the Iron and Steel Industry," to be held in London on 11th and 12th December, 1957.

BRITISH NUCLEAR ENERGY CONFERENCE

Report of Calder Hall Symposium

The Conference held a Symposium at Calder Hall in November, 1956, at which 19 papers were presented. These papers have now been published in the April issue of the *Journal of the British Nuclear Energy Conference*. They cover all the important features of planning, design, and construction of the Calder Hall nuclear power station. Copies of the issue are available from the Secretary of the B.N.E.C., 1–7 Great George Street, London S.W.1; the price to Members of The Iron and Steel Institute is 7*s*. 6*d*.

Forthcoming Meetings

Friday, 8th November: "Vacuum Techniques in the Atomic Energy Industry," by Dr. H. Kronberger (sponsored by the Institution of Mechanical Engineers): 6.30 p.m.

Thursday, 5th December: "Advanced Types of Power Reactor," by Dr. J. V. Dunworth, C.B.E. (sponsored by the Institution of Electrical Engineers): 5.30 p.m.

Both lectures are being held at the offices of the sponsoring institution.

AFFILIATED LOCAL SOCIETIES

East Midlands Metallurgical Society

At a Meeting of the Council on 9th July, 1957, it was agreed that the East Midlands Metallurgical Society should become an Affiliated Local Society of The Iron and Steel Institute. The President of the Society, Mr. N. S. Angus, A.MET., A.I.M., has been invited to serve as an Honorary Member of Council during his term of office. The Secretary of the Society is Mr. P. A. Blackwell, B.SC., 57 Derby Lane, Derby.

Vice-President of the Society is H. E. Gresham, B.SC., and the Committee consists of A. R. Bingham, E. Darley, P. R. Hinchcliffe, B.SC.TECH., Dr. H. K. Lloyd, M. McIntyre, B.SC., and T. Parry; the Treasurer is E. D. Knights, B.SC.

Lincolnshire Iron and Steel Institute

At a Council Meeting held recently, the President, Mr. C. T. Thomas, tendered his resignation, as he has moved to South Wales. Mr. A. H. Norris was unanimously elected to succeed Mr. Thomas. Three new Vice-Presidents were also elected: Mr. W. Campbell Adamson, Mr. H. C. Challinor, and Mr. A. Bridge.

EDUCATION

Iron and Steel Institute Prize

The Iron and Steel Institute Prize at Sheffield University for 1957 has been awarded to Mr. J. K. Wynn, who graduated with the degree of Bachelor of Metallurgy this year.

NEWS OF SCIENCE AND INDUSTRY

Associazione Italiana di Metallurgia

Dott. Prof. Guido Calbiani, Direttore Generale of the Società Dalmine, Milan, was elected in May to succeed Dott. Aldo Dacco as President of the Associazione Italiana di Metallurgia. Dott. N. Lo Pinto remains Secretary of the Association, whose offices are at Via Moscova 16, Milan.

Verein deutscher Eisenhüttenleute

The Eisenhüttentag and Annual Meeting of the V.d.Eh. are being held at Düsseldorf in October. A reception is being given for overseas visitors on Thursday, 23rd October, the following day will be devoted to technical sessions, and the general meeting will be held on Friday, 25th October.

Open Days at B.C.I.R.A. and B.W.R.A.

The laboratories of the *British Cast Iron Research Association* at Bordesley Hall, Alvechurch, Birmingham, were open for inspection on 3rd and 4th July, and a large number of visitors attended. On 3rd July the President of the Association, Mr. J. J. Sheehan, officially opened the new melting shop, which houses a comprehensive array of furnaces, including a battery of four high-frequency melting furnaces of 10, 5, 2, and 1 cwt capacities. The manifold aspects of the Association's work were on display, and of especial interest were the investigations into foundry atmosphere control and the determination of gaseous elements in cast iron.

Marshal of the Royal Air Force Lord Tedder was the guest of honour on 23rd July, when the laboratories of the *British Welding Research Association* at Abington, near Cambridge, were open for inspection. He officially opened the new metallurgical laboratory, which is extremely well equipped for the investigation of all the phenomena of welding. The building itself is of interest, since it is a welded portal frame structure, designed in accordance with the Plastic Theory by Professor J. F. Baker of Cambridge University; the Association has been providing financial support for the important work Professor Baker has been carrying out in the development of the Plastic Theory.

World's Largest Dragline

The world's largest walking dragline has recently gone into production at an opencast ironstone quarry near Stamford operated by the Ore Mining Branch of the United Steel Companies Ltd. The W1400, as it is called, was built by Ransomes and Rapier Ltd. and is electrically driven.

DIARY

29th Aug.–12th Sept.—ENGINEERING, MARINE, WELDING, AND NUCLEAR ENERGY EXHIBITION—Olympia, London.

2nd–6th Sept.—OPERATIONAL RESEARCH SOCIETY, OPERATIONS RESEARCH SOCIETY OF AMERICA, and INSTITUTE OF MANAGEMENT SCIENCES (U.S.A.)—International Conference on Operational Research—Oxford.

4th–11th Sept.—BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE—Annual Meeting—Dublin.

8th Sept.–9th Oct.—SIXTH COMMONWEALTH MINING AND METALLURGICAL CONGRESS—Vancouver, B.C., Canada.

8th–13th Sept.—AMERICAN CHEMICAL SOCIETY—132nd Meeting—New York.

17th–20th Sept.—INSTITUTE OF METALS—Autumn General Meeting—Glasgow.

18th–21st Sept.—INTERNATIONAL MINERAL DRESSING CONGRESS—Stockholm.

23rd–27th Sept.—ASSOCIATION BELGE POUR FAVORISER L'ÉTUDE DES VERRES ET DES COMPOSÉS SILICIEUX—Meeting on "Refractories in the Metallurgical and Atomic Energy Industries"—Brussels.

23rd–27th Sept.—NATIONAL FUEL EFFICIENCY SERVICE—4th Annual Course on "Current Practice in Fuel Efficiency"—Oxford.

23rd–26th Sept.—SOCIETY OF INSTRUMENT TECHNOLOGY—Conference on "Automatic Measurement of Quality in Process Plants"—University College, Swansea.

24th Sept.—THE IRON AND STEEL INSTITUTE—Autumn General Meeting—4 Grosvenor Gardens, London S.W.1.

25th and 26th Sept.—THE IRON AND STEEL INSTITUTE (Engineers Group)—Meeting on "Air Pollution in the Iron and Steel Industry"—Church House, Westminster, London S.W.1.

3rd Oct.—LEEDS METALLURGICAL SOCIETY—"Quantity Production of Grey Iron Castings," by P. A. Green—Chemistry Wing, the University, Leeds, 7.15 P.M.

7th–12th Oct.—SOCIÉTÉ FRANÇAISE DE MÉTALLURGIE—Journées Métallurgiques d'Automne—Paris.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

Contribution to the Study of the Lorraine Iron Basin. Part 2. M. Deudon, P. Emery and M. Febve (*IRSID publication*, 1957, Mar., pp. 59). An account of the Boulange Concession is given with analyses of the ores, including mineralogical findings, and reports of trials on beneficiation.

The Ore Deposits of Borovica in Bosnia (Jugoslavia): A Triassic Sulphide Deposit of the Rammelsberg Type. A. Cissarz. (*Z. Erzbergb. u. Metallhüttenwesen*, 1956, **9**, May, 225–231). A geological account on the formation of the lead–zinc–copper deposits of Borovica.—T. G.

Geology of the Kiernan Quadrangle Iron County, Michigan. J. E. Gair and K. L. Wier. (*U.S. Geol. Survey Bull.*, 1044). The iron-rich quartzite is described.

Pikes Peak Iron Deposits, Maricopa County, Arizona. L. L. Farnham and R. Havens. (*U.S. Bur. Mines Rept. Invest.*, 5319, Mar. 1957, pp. 31).

Mineral Resources of the San Carlos Indian Reservation, Arizona. C. S. Bromfield and A. F. Shride. (*U.S. Geol. Survey Bull.*, 1027–N). Small iron deposits occur, which are named and described.

Bibliography of Iron Ore Resources of the World. (To January, 1955). G. W. Luttrell. (*U.S. Geol. Survey Bull.*, 1957, No. 1019–D, pp. 187–371).

ORES—MINING AND TREATMENT

New Unloader Speeds Ore Transfer. (*Steel*, 1957, **140**, Mar. 18, 137). An unloader with a free-digging capacity of 1800 t/h is described unloading 20,000-t ships in 7 h.

Flotation of Iron Sulphides from Zinc Tailings of Southwestern Wisconsin, Lead-Zinc District. T. A. Evans, jun., J. W. Pennington and P. A. Wasson. (*U.S. Bur. Mines, Rep. Invest.*, 5324, Mar. 1957, pp. 9). A pilot-plant investigation is reported.

The Nature of Carphosiderite and Allied Basic Sulphates of Iron. A. A. Moss. (*Mineralogical Mag.*, 1957, **31**, Mar., 407–412). Carphosiderites and 5 or possibly 6 similar minerals are either jarosite or natrojarosite.

Prospects of Exploitation of Otanmäki Titanium Ore. O. Runolinna. (*Tek. Kemian Aikakausilehti*, 1957, **14**, Mar. 15, 107–110). [In Finnish]. Composition, mining, processing and utilization of an ore containing 35% magnetite, 28% ilmenite, 1% pyrite and silicates is described. The products are iron concentrates and sinter, V_2O_5, pyrites, ilmenite concentrate and crushed stone.

New Machine Sorts Dry Powder By Particle Size. (*Iron Age*, 1956, **178**, Dec. 6, 130–131). A new type of classifier built by Sharples Corp. will divide dry powder material into fine and coarse fractions in the range 15–110μ at rates up to 15 t/h. Details of the machine are given.—G. F.

The Three-Medium Heavy-Fluid Separation of Spathic Iron Ore at "Alte Hütte". W. Borek and F. W. Mayer. (*Z. Erzbergb. u. Metallhüttenwesen*, 1956, **9**, Aug., 363–367). The authors describe a lifting-wheel type of separator for siderite. The sp. gr. varies between 3·9 and 4·1; and that of the separation medium must be very high (3·55). The ferro-silicon used (44·7 vol.-%) must be spheroidal in order to obtain the high sp. gr. required. The throughput of the plant is 40–45 t per hr. Separation is very sharp. Design, operation, performance, and advantages of the plant are described in detail together with costs.—T. G.

Beneficiation of Iron–Copper Ores from Kasaan Peninsula, Prince of Wales Island, Alaska. R. R. Wells, E. G. Erspamer, and F. T. Stirling. (*U.S. Bur. Mines, Rep. Invest.*, 1957, No. 5312, Feb., pp. 15). Flotation and wet magnetic separation of calchopyrite-pyrites ore is reported.

Theoretical Studies of Magnetic Separation. I. Magnetic Forces of Mineral Particles and the Sensitivity of Magnetic Separation. S. Yashima. (*Tech. Rept. Tôhoku Univ.*, 1955, **20**, (1), 143–164).

FUEL—PREPARATION, PROPERTIES, AND USES

Some Basic Principles of Pulverization and Preparation of Coking Coal Blends. A. H. Brisse and H. E. Harris. (*Blast Furn. Steel Plant*, 1957, **45**, Mar., 301–307). Relation of degree of pulverization to coke strength and the effects of coal constituents are discussed. Hammer mill performance is reviewed with various screening and recycle systems and recommendations for preparations for grinding are made.

The Sink–Float Separation Plant at the Styria Erzberg. H. Mayr. (*Z. Erzbergb. u. Metallhüttenwesen*, 1956, **9**, Sept., 422–427). The author describes the sink–float separation plant at the Erzberg built in 1952 for a throughput of 125 t per hr. A new plant has recently been put into operation having a throughput of 400 t per hr. Design, operation, and

performance of the two plants are described in detail. Ferrosilicon is used as separation medium.—T. G.

The Problem of the Utlization of Anthracite in the Metallurgical Operations of Iron Smelting. L. Delvaux. (*Rev. Univ. Min.*, 1957, **13,** (9th Series), Feb., 57–83). A comprehensive study is presented of the physical instability of anthracite with rapid rise in temperature and the poor resistance to abrasion. These two factors restrict the use of anthracite in shaft furnaces. The causes of decrepitation are reviewed together with thermal pretreatments which have been suggested to reduce it. Results obtained on an experimental cupola with stablized anthracite are described. (33 references).—B. G. B.

Solid and Gaseous Fuels. Industrial Applications of Analysis Control and Instrumentation. W. H. Ode. (*Anal. Chem.*, 1957, **29,** Apr. Part II, 657–669). A review of analytical aspects 1953–1956. (295 references).

A New Coal Plastometer. D. C. Hills. (*Amer. Soc. Test. Mat. Bulletin*, 1956, Dec., 34–39).

Steel Works Coking Plant in Middlesbrough. (*Engineer*, 1957, **203,** May 10, 727–728). **Dorman Long Coke-Oven Plant Middlesbrough, Designed for Subsequent Duplication.** (*Engineering*, 1957, **183,** May 10, 588).

The Lecocq Coking System. A. C. Bureau. (*Gas World*, 1957, **145,** Apr. 6, 67–71). A twin-flue, integral underjet compound oven is described, with an account of various installations and their operation and advantages.

Method of Determining the Shrinkage of Coke. E. M. Taĭts and Z. B. Pechkovskaya. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 318–320). [In Russian]. The method of coke shrinkage determination described enables actual coke-oven conditions to be approximated and enables the dynamics of shrinking to be studied. The tests are carried out starting with a sample of the cold coal charge, which is heated through one face at a measured rate. A nichrome spiral is bedded in the sample and its compression, indicating the shrinkage, is recorded throughout the test. Results obtained with various blends of coal are given and some general principles deduced.—S. K.

Field Application of Direct Oil Firing and of Firing with Gas Produced from Oil. T. Narjes. (*Stahl u. Eisen*, 1957, **77,** March 7, 264–269). The author discusses the disadvantages connected with direct oil firing of O.H. furnaces such as atomizing of the oil, high air proportion, sulphur content and oil-coke formation. He then describes the O.C.C.R. oil carburetter in which the oil is mixed with air at about 1200° C, cracked and partly burned. The resulting hot gas contains about 16% CO, 14% H_2, 4% CH_4 and 4% CO_2. The sulphur of the oil is apparently fixed as the neutral compound carbon oxysulphide.—T. G.

A Systematic Analysis of Deposits from Oil-Fired Furnaces. J. W. McCoy. (*Amer. Soc. Test. Mat. Bull.*, 1957, Apr., 59–63). 11 Metals are determined on 2 g of extracted residue by the methods given.

Gas Firing for Furnaces. A. Higgs. (*Metal Ind.*, 1957, **90,** Apr. 19, 310–312; Apr. 26, 332–334). Mainly non-ferrous installations are briefly described.

A Survey of the Distribution of Organic Sulphur Compounds in Town Gas. Joint Research Committee of the Gas Research Board and Univ. Leeds. (*Trans. Inst. Gas Eng.*, 1945–46, **95,** 363–400).

The Removal of Hydrogen Sulphide from Fuel Gases. G. V. Hopton and R. H. Griffith. (*Trans. Inst. Gas Eng.*, 1945–46, **95,** 159–180). A review of the process using iron oxides.

The Removal of Sulphur Compounds from Coal Gas and Synthesis Gas at Atmospheric Pressure. Joint Research Committee of Gas Research Board and Univ. of Leeds. (*Trans. Inst. Gas Eng.*, 1945–46, **95,** 210–250).

TEMPERATURE MEASUREMENT AND CONTROL

Measurement of Liquid-Steel Temperature. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 259–261). [In Russian]. The importance of correct measurement of liquid-steel temperatures is discussed and the present state of thermocouple techniques briefly considered. Organization and costs of large-scale measurements are also mentioned.—S. K.

Industrial Measurement of Gas Temperature. (*Brit. Coal Utilisation Res. Assoc. Quart. Gazz.*, 1957, (30), 3–7). Variations found in measurements are mentioned and three probe-type instruments are described: the suction pyrometer, Total Heat Meter, and Venturi Pneumatic Pyrometer. The use of the last-named in the Bessemer flame is shown.

REFRACTORY MATERIALS

Canadian Kyanite as a Raw Material for the Production of High-Grade Refractories. V. D. Svikis. (*Refract. J.*, 1957, **33,** Mar., 102–110). Deposits are briefly reviewed and experimental firings at 1600° are tabulated, showing properties and effects of particle size, forming pressure and calcination temperature and recommendations are given.

Improvements in the Quality of Silica Roof-Bricks. W. M. Fern. (*Trans. Brit. Ceram. Soc.*, 1957, **56,** Mar., 110–132). Advantages were found in changing from high to low alumina roof blocks though the effects of improvements are only shown in severe operating conditions. A drop of Al_2O_3 content of 0·1% was shown to correlate with a decrease of 1·0% in apparent porosity. The best blocks had 0·2% Al_2O_3, $< 0·10$% alkali and < 20% apparent porosity so that decrease of porosity is one of the few remaining expedients for improvements.

Improvements and Modern Tendencies in the French Refractory Industry. L. Halm. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14,** 157–167). A general review of the French refractory industry is presented.—B. G. B.

Study of Refractories for Open Hearth Steel Ladles. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13,** 2457–2467). The results of trials carried out with various refractory compositions in ladles are reported and a review of the conditions of service made. The economic importance of minimizing wear on ladle linings is stressed. The results of laboratory tests made on the refractory materials used in trials are reported.

An Enquiry into the Consumption of Bricks in Mixers. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14,** 139–141). A report is given of a discussion on the lining life of mixers. Results obtained from 22 firms are given in tabular form and vary between 0·15 and 0·75 kg bricks/tonne iron.—B. G. B.

Apparatus for Determining the Thermal Conductivity of Refractories. D. M. Shaktin. (*Zavodskaya Laboratoriya*, 1956, **22,** (7), 869–871). [In Russian]. A new design of thermal conductivity apparatus for comparatively small (50 mm dia, 56 mm height) samples of refractories is described. Carborundum is used for measuring the heat flux, enabling mean and hot-face temperatures to be raised to 900–1100° C and 1200–1250° C, respectively. Measurements are made under stationary state conditions with heat loss compensation and for calibration, iron of known conductivity is used. The accuracy of results is $\pm$ 6%. Conductivity *v.* temperature curves for magnesite and fire-clay bricks up to mean temperatures of 1100 and 900° C, respectively, are given.—S. K.

High Speed Guarded-Hot-Plate Apparatus for Thermal Conductivity of Thermal Insulation. E. V. Somers. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** Aug., 1291–1296). A thermal-conductivity apparatus for the accurate determination of the K-factors of thermal insulation in 15 mins is described. The apparatus combines the use of a heater plate of very low thermal capacity with separate automatic control of the power to the central and guard-ring heaters, obtainable with commercially available power-control apparatus.—D. H.

Contact Phases between Portland Cement and Basic Furnace Linings. F. Trojer. (*Silicates Indust.*, 1957, **22,** Mar., 141–144). [In German]. At sintering temperature the main crystalline component in bricks of Radex A quality—mainly periclase—remains unchanged, but at contacts of crystalline and vitreous clinker phases the hot face of the bricks is modified. Penetration towards the cold face is limited to 30–70 mm and the general compositions of the layers found are given. Effects in furnace operation are described and illustrated and careful control is necessary if deterioration is to be retarded.

Standardisation of Tests on Refractory Products in the European Area. J. Baron. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13,** 2447–2456). Standard procedures for testing the properties of refractory materials are presented in detail in tabular form and the proposals are briefly discussed.—B. G. B.

Spectrum Method for the Analysis of Magnesite and O.H. Bottom Fettling from Solutions. N. V. Kandler, A. V. Mitroshina, and I. L. Shmulenson. (*Zavodskaya Laboratoriya*, 1956, **22**, (4), 440–441). [In Russian]. A spectrum method for the determination of magnesia in magnesite and O.H. fettling in concentrations of 20–95% with an accuracy of 2–4% (relative) is described. Solutions of the samples are used.—S. K.

IRON AND STEEL—GENERAL

Research Work at the Kuznetsk Metallurgical Combine. P. S. Plekhanov. (*Stal'*, 1956, (8), 744–746). [In Russian]. Work carried out during 1955 by the various laboratories of the major steel centre in Siberia is reviewed. This contributed to improvements in sintering, blast-furnace, steel-melting, heating and rolling practice.—S. K.

Research Work at the "Azovstal'" Works. M. T. Bul'skiĭ and M. P. Sidel'kovskiĭ. (*Stal'*, 1956, (8), 746–748). [In Russian]. Recent work by the central laboratory at the Azovstal' works, some in co-operation with other organizations, is described. This included a comparative study of blast-furnace operation with high top-pressure, the use of constant humidity blast, furnace operation with the addition of dolomitized limestone, the production of fluxed sinter from new materials; the intensification of O.H. furnace operation by oxygen blowing, increases in ingot weight, organization of the O.H. shop; improvements in the design of tilting O.H. furnaces and soaking pits; improvements in rolling practice; and the solution of various problems associated with steel quality.—S. K.

Research Work at the Dzerzhinskiĭ Works. M. P. Kuznetsov, G. N. Rekhlis, I. G. Polovchenko, T. A. Kramnik, B. I. Emlik, V. I. Baptizmanskiĭ, N. G. Sorochan and B. L. Poletaev. (*Stal'*, 1956, (8), 749–750). [In Russian]. The central works laboratory has helped in the adoption of low-manganese pig-iron production and utilization, developed a standard sinter-reducibility determination method, contributed to improved Bessemer steel and rolled strip quality and to fuel economy.—S. K.

Research Work at the Zlatoust Metallurgical Works. V. N. Davidyuk. (*Stal'*, 1956, (8), 751–755). [In Russian]. The research work at the Zlatoust works has concentrated on steel melting and metallographic aspects—the use of low-manganese pig iron in the scrap process, the study of conditions leading to the appearance of defects and the nature of various structural and mechanical peculiarities in steels.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Metal Structure of the Highest Czechoslovak Blast Furnace and Associated Installations. G. Novotny (*Acier-Stahl-Steel*, 1957, **22**, Apr., 145–153). An illustrated account of the construction, with diagrams and all dimensions of a new furnace, with its stoves, charging equipment, Lurgi gas purifiers and blast heaters.

Design of Blast Furnaces with a Thin-Walled Stack. S. Chernokh. (*Stal'*, 1956, (8), 682–689). [In Russian]. Experience in Czechoslovakia on blast-furnace operation with thin-walled stacks is critically reviewed, with special attention to the shell construction. In the most recent furnace to go over to the use of thin-walled stacks the refractory lining (one brick width thick) is supported on inclined metal ribs welded to the shell. Water cooling of ribs is provided for in the latest design. Thin-walled stacks have, on the whole, proved a success under conditions in Czechoslovakia, but as pointed out editorially, this has not been so in Western Germany.—S. K.

Proposal for a Self-Lining Blast-furnace. W. A. Archibald, T. P. Brown, and L. A. Leonard. (*J. Iron Steel Inst.*, 1957, Sept., **187**, 32–45). [This issue].

On Assessing the Quality of Agglomerates. J. Duda. (*Hutník*, 1956, **6**, (9), 262–265). [In Czech]. It is shown, on the basis of the author's work, that satisfactory quality estimates on blast-furnace agglomerates are obtainable from their chemical composition, crushing strength and granulometry. The "Rubin" rotary drum was found to provide the most suitable means for testing their resistance to mechanical damage.—P. F.

Injection of Powdered Fuel into the Blast-Furnace Hearth. V. I. Loginov, G. G. Oreshkin, I. G. Polovchenko, A. A. Sorokin, and I. N. Kardasevich. (*Stal'*, 1956, (8), 675–682). [In Russian]. An account is given of trials on a relatively small (427 m³ useful volume) blast furnace smelting ferro-silicon in which low-grade anthracite dust was injected through the tuyeres with the aid of a special installation. In some of the trials gas sampling of the combustion zone with and without the injection was carried out. 20 t/hr of the powdered fuel could be injected without difficulty, equivalent savings in coke being achieved. In spite of the high (16–18%) ash and sulphur (1·7–3%) contents of the fuel the ferrosilicon quality improved and the furnace continued to function smoothly.—S. K.

Geometrical Study of the Distribution of the Burden in the Throat (of a Blast Furnace) after Lowering the Bell. G. Aúbert. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956; **13**, 2391–2402). Factors controlling the thickness of the various burden materials across the diameter of the throat of a blast furnace are examined geometrically from the knowledge of their angle of rest. The results obtained are considered in the light of those obtained in practice at No. 4 furnace Mont Saint Martin.—B. G. B.

Blast Furnace Goes Push-Button. (*Iron Age*, 1957, **179**, Mar. 28, 69). A note on the automation of a furnace for U.S. Steel Fairless works.

Closer Control for the Blast Furnace. (*Steel*, 1957, **140**, Apr. 8, 100). See preceding abstract. The equipment is supplied by Cutler-Hammer Inc. Milwaukee.

Full Use Must be made of Labour-Productivity Reserves in Blast-Furnace Plants. A. I. Naprasnikov. (*Stal'*, 1956, (8), 738–739). [In Russian]. The employment of labour at 25 Soviet blast-furnace plants is analysed and critically compared. The work at the furnace is divided into ten groups, the distribution of labour between them for each plant being tabulated.—S. K.

Summary of Research on the Ougrée Low Shaft Furnace. (*Rev. Univ. Min.*, 1957, **13**, (9th Series), Feb., 84–90). An illustrated review of recent modifications made to the International Low Shaft blast-furnace in Belgium is presented. The results obtained during three year's operation are briefly considered.—B. G. B.

Latest Developments in Electric Pig Iron Smelting. K. Sandvold. (*J. Electrochem. Soc.*, 1956, **103**, Dec., 696–699). A description of the layout and operation of plant using three 20,000 kW Tysland-Hole furnaces at the Mo i Rana works of A/S Norsk Jernverk in Norway.—A. D. H.

Note Concerning the Measures Taken by the Aciéries et Minières de la Sambre (A.M.S.) to Increase Mixer Lining Life. Defoin and Demarez. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14**, 147–151). Excessive erosion of the joints between the brickwork of a 320 tonne mixer led to a study of factors causing the wear. This was found to be due to the presence of blast furnace and soda ash slag entering the mixer with the iron. By the addition of 60 kgm of powdered lime per 20 tonnes of metal the slag viscosity could be raised and wear of refractories reduced. A CaO/SiO_2 ratio of 1 is aimed for in the mixer slag.—B. G. B.

PROPERTIES, TREATMENT AND USE OF SLAGS

Evaluation of Granulated Slag as an Enriching Addition to Natural Sands in Cement-Concrete. M. Yu Leshchinskiĭ. (*Zavodskaya Laboratoriya*, 1956, **22**, (6), 698–700). [In Russian]. Additional tests on granulated blast-furnace slag are described which enable the nature of its porosity and mechanical properties to be evaluated with a view to its use, together with fine-grained natural sands, in concrete.—S. K.

The Effect of Zinc Oxide and Zinc Sulphide (on the Viscosity) of Molten Slags. F. Johannsen and K. Holler. (*Z. Erzbergb. u. Metallhüttenwesen*, 1956, **9**, Nov., 511–522). The effect of ZnO and ZnS on the viscosity and m.p. of slags was studied in the following systems: $FeO–SiO_2 + CaO.SiO_2$ and $FeO–SiO_2 + CaO + Al_2O_3$. The results are presented in tables, graphs, and photomicrographs.—T. G.

Constitution and Properties of Slags from Smelting Processes. I.—The Viscosity of Slags of the System $FeO–Al_2O_3–SiO_2$. P. Röntgen, H. Winterhager, and R. Kammel. (*Z. Erzbergb. u. Metallhüttenwesen*, 1956, **9**, May, 207–214). The viscosity of synthetic slags of the systems $FeO–SiO_2$ and $FeO–Al_2O_3–SiO_2$ were measured. The results indicate that

the constitution of the slags is very similar in both solid and the liquid states and that the solid-state bonding forces are still present and active in the liquid state. The results are presented in tables, graphs, and many constitutional diagrams. (29 ref.).—T. G.

DIRECT PROCESSES

Direct Steel. (*Indust. Bull. of A. D. Little Inc.*, 1956, (33), Dec. 3–4). A brief note on recent possibilities is given, mainly of fluid-bed processes, with notes on the limitations of the blast-furnace.

PRODUCTION OF STEEL

The Importance of Scrap to Pig Iron and Steel Production. K. Martin. (*Stahl u. Eisen*, 1957, **77,** March 7, 259–264). The author presents a statistical analysis of the quantities of scrap available in the world for use in the iron and steel industry and of the quantities and proportions of scrap used in various countries as well as the effect of the use of scrap on coal production and coke consumption. In Germany, about 430 kg. scrap per t of steel is used and this amount has been almost constant since the end of the War.—T. G.

New Developments in Ore Reduction and Steelmaking. H. B. Emerick. (*Blast Furn. Steel Plant*, 1957, **45,** Mar., 313–318, 344). The importance of physical chemistry in metallurgy is noted and the fluidized reduction process including the H-iron process, vacuum methods, ore beneficiation, desulphurization, oxygen furnace processes, L.D., Kal-Do and Rotor systems, oxygen in the O.H. furnace and casting techniques aimed at cracking and surface defect prevention. Finally, continuous casting is briefly discussed.

A New Process For Improving the Blowing of the Basic Bessemer Converter. B. Trentini, P. Vayssière, D. Jorre, and M. Gombert. (*Rev. Met.*, 1957, **54**, Feb., 147–158). This new process consists in injecting at the beginning of refining a certain quantity of lime powder in the air blast. This is found to prevent the foaming of the primary slag and to prevent undue slopping. This technique enables an increased weight of metal/charge to be used. Irons high in silicon can be refined and the maximum limit of the silicon content for basic Bessemer iron practically disappears. This technique in conjunction with changes in converter lines already published by I.R.S.I.D. enable great increases in steelmaking capacity to be obtained from existing steelworks.—B. G. B.

Particulars of the Temperature of Basic Converter Melts Towards the End of the Dephosphorization Period. H. vom Ende. (*Stahl u. Eisen*, 1957, **77,** Feb. 21, 224–225). The author reviews a report by Trentini (*Circ. Inform. techn.*, 1955, **12,** (12), 2379) on temperature measurements of basic converter melts beyond the time of the drop of the carbon flame up to the end of the dephosphorization period. The temperature rises during this period almost linearly and shows a sharp arrest point at the end of the dephosphorization period. The practical application of this phenomenon with respect to blowing time is discussed.—T. G.

Oxygen Application in the Basic-Bessemer Process. Developments in France. M. Michaud and M. Zehringer. (*Iron Coal Trades Rev.*, 1957, **174**, Apr. 26, 979–984). The Basic Bessemer process is reviewed with reference to P and N removal, and the uses of oxygen discussed. Oxygen enrichment to 25–40% or the use of O_2–CO_2 or O_2-steam are mentioned and thermal freedom, improved heat balance and high converting capacity are achieved. The L-D and Kalling and Rotor processes are also mentioned and ladle pre-refining. Oxygen supply is then considered in greater detail, distribution by pipeline and integrated generator supply being dealt with. (8 references).

Steel Industry Utilizes Larger Open Hearths to Increase Tonnage. (*Indust. Heating*, 1957, **24,** Mar., 532, 534). Recent large furnaces installed in U.S. are briefly reviewed. The Weirton Steel Co. 600 ton furnace is particularly dealt with.

Automation of the O.H. Furnaces at the "Zaporozhstal' Works. B. V. Kioresko, V. F. Gusev, A. L. Turubiner, G. A. Molotkov and A. I. Savin. (*Stal'*, 1956, (8), 689–697). [In Russian]. An account is given of the system developed and applied at the Zaporozhstal' works for the automation of O.H. furnace operation, on which intensive work has been in progress for some years. At present two of the furnaces, working on mixed gas, are fitted with the latest system which includes programmed regulation of thermal conditions to suit the particular stage of the process, regulation of reversals and of pressure in the furnace. Details are given of the devices used, and their interconnection, and of results obtained. Desirable modifications are outlined.—S. K.

New Developments in Oil Firing the Open Hearth Furnace. M. W. Thring. (*Technology*, 1957, **1,** May, 104). Model and full-scale investigations of flow and erosion, and of heat transfer and flame emissivity are briefly reported.

Maintaining the Open Hearth. Basic Inc. (*Steel*, 1957, **140,** Mar. 4, 102, 105, 106, 108, 110, 112). A chapter from a manual. General information on repairs is briefly given.

Ways of Lowering the Cost of Open-Hearth Furnace Repairs. G. I. Popov. (*Stal'*, 1956, (8), 740–741). [In Russian]. An account is given of organizational improvements for the cold repair of O.H. furnaces which have accelerated this work, reduced refractory consumption and increased labour productivity.—S. K.

Basic Checkers. J. Mackenzie. (*Refract. J.*, 1957, **33,** Mar., 100–101). Higher temperatures and erosion by iron oxides carried over produce increased erosion and alternatives to fireclay or silica are high-alumina and basic refractories. The latter were discussed. Chrome-magnesite bricks were regarded as undesirable and magnesite or forsterite were expected to serve best. Trials on slag-resistance were reported and magnesite appeared to be suitable.

Technical and Economic Characteristics of Heat Regenerators. R. Kremer. (*Hutnik*, 1956, **6,** (9), 265–268). [In Czech]. The thermal and economic efficiency of regenerators, particularly for use with O.H. furnaces, are discussed in relation to the most important characteristics of design and operating conditions. The author considers that metal recuperators will gradually displace regenerators.—P. F.

Gas Flushing of Molten Steel. C. H. Wyman. (*Trans. Amer. Found. Soc.*, 1956, **64,** 62–71). The research programme is set out and findings to date are reported. Using 275-lb monorail and 5-t teapot ladles trials were made with gas flush only, gas flush + deoxidizer injection and manual deoxidation compound additions. A was used through a ¾-in. pipe for 21–65 sec. at 25–35 ft^3/h. Deoxidizers were added at 4 lb/t + 0·085% Al during 21–65 sec. Materials added were CaMnSi, CaSi, CaSiCe, CaSiAl, CaTiSi and CaMgFeSi, C_2F_4 was also used for flushing and segregations and effects of N_2 on Charpy values were investigated. Many structures are shown and quality factors are evaluated and related to processes and additions.

Design and Performance of Modern 70-ton Arc Furnaces for Steel Making. E. Pakulla. (*Stahl u. Eisen*, 1957, **77,** Feb. 21, 197–204). Design, plant layout, and performance of two 70-ton arc furnaces at Deutsche Edelstahlwerke Krefeld are described. The vessels have a max. dia. of 6200 mm and an input of 15kVA. each. The power factor varies between 0·87 and 0·91. The life of the lining is discussed. The average output per charge is 69·7 tons, tapping-to-tapping time is 7 hr 12 min, and average output per hr 9·64 tons. Total power consumption is 614 kWh per ton, 458 kWh per ton is used for melting down. The performance data are compared with a 70-ton furnace at Samuel Fox & Co., Ltd., Stocksbridge, as well as with American furnaces. Costs are analysed for various modes of operation and, finally, performance of O.H. and arc furnaces is compared.—T. G.

Carriage of Hot Metals by Rail. Special Methods Developed by French National Railways. (*Rail. Gaz.*, 1957, **106,** Apr. 19, 452). Hot steel for lamination, which is not allowed to fall below 932° F, is carried for 16 hr in special wagons. Other special wagons and ladle-carrying trucks carry molten metal 6¼ miles.

Making Quality Leaded Steels (*Steel*, 1957, **140,** Mar. 11, 162–166). The control of quality in the casting of leaded steels is discussed, with particular emphasis given to the rate, timing, uniformity, and dryness of the lead feed by the air gun. The use of the X-ray spectrograph in analysis control is also described.—G. F.

Production of Rimming Steel with the Addition of Ferromanganese to the Ladle. I. S. Marakhovskii and V. F. Mazov. (*Stal'*, 1956, (8), 697–699). [In Russian]. Good results have been obtained in the production of rimming steel by adding ferromanganese to the ladle only. The ferroalloy must be added in 100-mm pieces and must contain under 1% Si.—S. K.

Hot Work Steels for Aircraft Structures. E. A. Loria. (*Mat. Methods*, 1957, **45**, Mar., 115–119). Elevated temperature properties of 3 steels are given up to 1200° F, stability after heating at 1000° F for up to 100 hr and similar treatments is given and creep properties are shown.

Ship-Plate and Constructional Steels. A. M. Sage. (*Iron Coal Trades Rev.*, 1957, **174**, Apr. 12, 849–852). The improvements in converter steel due to oxygen blowing, producing much lower nitrogen contents, or L-D and similar process steels may compete with O.H. steel for ship and large tank construction. Ingot casting for rolling mills is considered, including continuous casting. Recent rolling mill installations are mentioned, and steel specifications and compositions are reviewed with respect to killed steels and brittle fracture testing.

Questionnaire on Ingot-Moulds. J. Duflot. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14**, (2), 347–353). A review of trends in ingot-mould consumption is presented. Variations in mould life and factors influencing mould life are considered. The results obtained in France are compared with those obtained by B.I.S.R.A. in Great Britain.—B. G. B.

Continuous Casting Comes to Carbon Steel. (*Steel*, 1957, **140**, Mar. 25, 108, 110, 114). The present economics of the process are briefly indicated but difficulties are mentioned which might deter construction of plants. A table shows all the continuous casting installations now known to be in operation, 24 in all, of which 7 are experimental.

Continuous Casting. (*Mech. World*, 1956, **136**, Aug., 357–358). The history of the subject is outlined and the various processes discussed.—D. H.

Instrumentation for Temperature Control Guides Continuous Casting. (*Indust. Heating*, 1957, **24**, Mar., 522–524. 526. 528). In the Atlas Steels plant measurements are made of molten metal temperatures in ladle, tundish and mould and controls of ladle tilt, machine speed, cooling water inlet and outlet temperatures, slab surface temperature and machine speed. These are discussed.

Henningsdorf Institute for Steel Research in 1955, E. Maurer. *Technik*, 1957, **12**, Feb., 79–88.) Work at the above Institute is reported. This includes studies of lamination in structural steel sheet, development of a high temperature boiler steel, research on electric transformer sheet steel, and the examination of a variety of ad hoc industrial problems.

PRODUCTION OF FERRO-ALLOYS

Use of Electric Furnaces in Ferroalloy Research. N. B. Melcher. (*J. Electrochem. Soc.*, 1956, **103**, Dec., 691–695). A review of the electric furnace equipment used by the U.S. Bureau of Mines for pilot plant studies of ferro-alloy smelting.

Key to Low Recovery Costs. Now Winning Ferromanganese from Low-Grade Ore in a Prototype Plant, the New Udy Furnace Could Tap Virtual Mountains of Other Low-Grade Ores and Wastes. (*Chem. Eng.*, 1957, **64**, Apr., 166, 168). **Ferromanganese Plant at Niagara Falls.** C. Mamen. (*Canad. Min. J.*, 1957, **78**, Mar., 70–72).

A Process for the Manufacture of Aluminium Alloys with High Melting-Point Elements. F. Erdmann-Jesnitzer and K.-H. Erler. (*Aluminium*, 1956, **32**, Nov., 712–716). It is concluded from the test results reported that it is possible to alloy high-purity aluminium with iron and other metals by scattering a mixture of metallic oxide and aluminium flakes on the molten metal surface and igniting it by means of an electric arc.—L. J. L.

FOUNDRY PRACTICE

The Foundry Industry of Finland. E. Autere. (*Foundry Trade J.*, 1957, **102**, Apr. 25, 501–508). Sources of raw materials and power are outlined and the main foundries briefly described.

Refractories in the Foundry. J. H. Cannon and A. L. Bradley. (*Engineer Foundryman*, 1957, **21**, Jan. 60–64; discussion 64–65). Physical and chemical factors controlling the attack on cupola and converter lining materials are explained.—A. D. H.

The Use of Gas as a Fuel in Foundries. (*Indust. Gas*, 1956, **19**, Aug., 347–352). The main uses and advantages of town gas in ferrous and non-ferrous foundries are described.—D. H.

What the Engineer Expects from a Casting. L. B. Knoll. (*Engineer Foundryman*, 1957, **21**, Mar. 56–62). Advantages of casting and the reasons for its preference to or rejection in favour of wrought products are discussed. Factors and control processes tending to produce satisfactory castings of high quality and good mechanical properties are reviewed. South African labour was referred to in discussion.

Tin Is Not a Subversive Element in Grey Iron. J. A. Davis, D. E. Krause, and H. W. Lownie, jun. (*Mod. Castings*, 1957, **31**, May, 96–98). Tin is shown to promote a pearlitic structure and to promote wear resistance and machinability. 0–0·5% Sn was added to melts of hypo- and hyper-eutectoid irons specially made up and the mechanical properties and micro-constituents were examined. Structures are shown.

Hot Blast Cuts Foundry Costs. C. F. Joseph. (*Steel*, 1957, **140**, Mar. 11, 159–160). The advantages to be gained by preheating cupola air blast are discussed briefly, and examples of the benefits are indicated by the case histories of two malleable foundries before and after conversion to hot blast.—G. F.

Fluxes and Slags in Cupola Practice. (*Bradley's Mag.*, 1957, Spring, 3–4). Limestone and its alternatives are discussed, lime, chalk, dolomite and fluorspar and soda ash. Compositions and properties of cupola slags are briefly reviewed.

Cupola with Continuous Slot Tuyeres with Regulated Blast. A. A. Anan'in and V. P. Chernobrovkin. (*Liteinoe Proizvodstvo*, 1956, (1), 10–13). [In Russian]. A recently installed cupola with a new tuyere arrangement is described in which the blast is distributed evenly around the whole periphery of the cupola and provision is made for accurately calculating the air flow to the different tuyere rows and to individual tuyeres. Data are presented showing the effect of changing tuyere practice on iron temperature and productivity. Highest productivity (920 kg/hr) was obtained with all the blast valves fully opened, giving 26% of the blast through the first (lowest) row, 31% through the second and 43% through the third row.—S. K.

Life of the Oxygen Tuyere in the Treatment of Cast Iron in the Cupola Fore-Hearth. M. D. Lifshits. (*Liteinoe Proizvodstvo*, 1956, (1) 27–29). [In Russian]. A full scale investigation is described on the behaviour of various types of tuyere for oxygen-blowing the metal in the manufacture of magnesium-inoculated cast iron. Fireclay, chrome-magnesite, magnesite and dinas bricks for tuyere lining were compared. The oxygen at 6–7 atm. was blown through a 3-mm dia. tube into the cupola forehearth producing 3–3·5 t/hr, the iron temperature rising to 1460–1490° C. An improved tuyere construction and operating procedure has been developed permitting the adoption of a two-shift system. The procedure involves deliberate increase in local wear at certain points, giving greater overall service life.—S. K.

Chill Casting in the Malleable Iron Foundry. K. Stölzel. (*Giessereitechn.*, 1956, **2**, Oct., 233–235). Examples are given to show that chill casting can be used in malleable iron foundries provided the castings and the moulds are expertly chosen and designed.—L. J. L.

The Present State of Development and Future Trends in Chill Casting. F. Naumann. (*Giessereitechn.*, 1956, **2**, Oct., 217–220). Chill casting production in the East German Republic will amount to 8000–10,000 tons in 1956. Production planned for 1960 is 180,000 tons, amounting to 15% of total production. The method lends itself to automation. The technical and economic advantages are outlined.—L. J. L.

Some Comments on "Chill Castings." R. Keilitz. (*Giessereitechn.*, 1956, **2**, Oct., 220–224). Some preliminary results are reported of tests on four circular castings produced by different methods. Measurements of hardness and density have demonstrated the high quality of chill castings.—L. J. L.

Chill Casting in the Production of High-quality Cast Iron. E. Bakovsky. (*Giessereitechn.*, 1956, **2**, Oct., 225–233). A survey is given of cast iron components produced by chill casting methods; the various methods are described and compared; future developments and applicability of chill casting techniques to series production are discussed, and the causes of and remedies for waste are examined.—L. J. L.

Chilled Cast Iron for Glass Moulds. L. A. L. Santos. (*Bol. Assoc. Brasil. Met.*, 1955, **11**, Oct., 381–387). [In Portuguese]. The use of a cast iron core in moulds for casting moulds for bottle-making is described. A high quality surface is required for this and the chill on the inner surfaces gives rise to a suitable fine-grain, close layer of grey cast iron. This layer

was found to be about 12 mm thick in irons of the type 3–4% C, 1·5–2% Si, with a Ni : Cr ratio between 1·0 : 0·35 and 2·0 : 0·75. White cast iron is not required, and any that is formed can be removed by the stress-relieving treatment.

Investigation on Cast Iron Having Fine Graphite Produced by Melting Cast Iron Covered with Slag Containing TiO_2. VI. Determination of Metallic Titanium and Non-metallic Titanium Compounds Contained in S-H Cast Iron. M. Tsuda. (*Tetsu to Hagane*, 1956, **42**, Mar., 231–234). [In Japanese]. An analytical scheme is presented for determining metallic titanium, TiN, TiC, and the oxides (with sulphides) of titanium.—K. E. J.

Investigation on Cast Iron Having Fine Graphite Produced by Melting Cast Iron Covered with Slag Containing TiO_2. VII. Thermodynamic Study on Titanium Contained in S-H Cast Iron. T. Mori. (*Tetsu to Hagane*, 1956, **42**, Mar., 234–235). [In Japanese]. Data are given for the reactions of titanium with carbon and nitrogen, and a diagram expresses the relationships between titanium and carbon in the metal, TiC and TiN at temperatures between 1100° and 1800° C.—K. E. J.

Influence of Alloying Elements and Inoculations on Slowly Cooled Cast Iron. S. Tsutsui. (*Tetsu to Hagane*, 1956, **42**, Mar., 308–309). [In Japanese]. The experiments were made in a graphite spiral furnace, which is described, using C, Si, Mn, P, S, Cu, Ni, Cr, Mo and V.—K. E. J.

The Effect of Nickel and Chromium on Chilled Layers of Alloy Iron. K. Otani. (*Tetsu to Hagane*, 1956, **42**, Mar., 304–306). [In Japanese]. The effects of nickel and combined carbon contents on the structure and hardness of the chilled layer are considered, as is the effect of chromium on the cementite volume of the chilled layer.—K. E. J.

Effects of Calcium Silicide and Calcium Fluoride etc. [when Injected into] Cast Iron. T. Kusakawa *et al.* (*Tetsu to Hagane*, 1956, **42**, Mar., 295–297). [In Japanese]. Injections of calcium silicide, together with calcium fluoride and rare-earth oxides in amounts up to 7·0% (total), were made with specially-designed equipment. In general the tensile strength increased with each addition, the max. value of 58·5 kg/mm² being obtained with 2·0% Ca_2Si and 0·2% rare-earth oxides. The graphite structure is noted for each case.—K. E. J.

Fundamental Studies on Spheroidal Graphite Cast Iron. XII. Influence of Si on the Formation of Spheroidal Graphite Cast Iron. R. Okazi. (*Tetsu to Hagane*, 1956, **42**, Mar., 309–310). [In Japanese].—K. E. J.

Fundamental Studies on Spheroidal Graphite Cast Iron. XIII. Influence of Cr on the Formation of Spheroidal Graphite Cast Iron. R. Okazi. (*Tetsu to Hagane*, 1956, **42**, Mar., 311–312). [In Japanese]. In these experiments the chromium content was varied up to approx. 5% in a series of irons containing the following respective proportions of total carbon and silicon: 4 and 1·8%, 4 and 2·4%, 4 and 2·9%, and 3·4 and 1·8%.—K. E. J.

A New Composition for Fast Malleable. A. L. Boegehold. (*Metal Progress*, 1956, **70**, Oct., 73–74). The usual form of pearlitic malleable iron is unsuitable for section thicknesses much greater than $\frac{3}{4}$ in. By the addition of 0·025% Bi and 0·0003% B a section up to 5 in. can be cast without mottle. This enables the iron to be used for crankshafts or other heavy-section castings.—B. G. B.

Recent Developments in the Field of Steel Casting. W. A. Stauffer. (*Giesserei*, 1956, **43**, Aug. 30, 508–519). The types of steel used in steel founding and their applications are first described. These include unalloyed, low-alloy, and high-alloy steels. The methods of melting and heat treatments required are reviewed. The properties of steel castings described include the hot strength, resistance to scaling, cavitation, attack by drops, and wear and fatigue by corrosion. The testing methods for castings are also described.—R. J. W.

Moulding Technique for a Large Steel Casting. R. C. Taralli. (*Bol. Assoc. Brasil. Met.*, 1956, **12**, Apr., 117–124). A pump-body casting, 2·5 m dia., 8,600 kg weight was required but because a full pattern would be too expensive and because the moulders were inexperienced in skeleton moulding, a scheme was evolved using a half-pattern. From this the lower half of the mould and then the core was made and these were then used to make the upper half of the mould. No core box was necessary. Steps in the process are illustrated.—P. S.

Steel Castings Manufacture: Control Factors. E. Longden. (*Iron Steel*, 1956, **29**, Sept., 415–421; Oct., 457–462). The author outlines systematic controls of the vital stages in manufacture necessary to produce steel castings to required dimensions, soundness, general quality, and costs. Taking the example of a steel gear, he discusses progressive freezing and the importance of correct gating and feeding. Control charts designed to cover the complete requirements of feeder heads and padding aids are given, and the allowances for contraction, machining, and manufacturing errors, are discussed.—G. F.

Moulding Characteristics of Madras Silica Sand. B. V. Somayajulu and B. R. Nijhawan. (*J. Sci. Indust. Res.*, 1956, **15A**, Nov., 508–512). Standard tests for steel-casting quality were carried out. The material was rather coarse for precision casting.

The Action of Water on Bentonite and Foundry Sands. V. Montoro. (*Fonderia Ital.*, 1956, **5**, April, 133–138). [In Italian]. The author shows that when foundry sands have really uniform characteristics the cohesive properties of the mixtures can be determined with adequate accuracy by the ratio of the moisture to the bentonite. Details are given of the tests carried out, of the nature and characteristics of the sands and bentonites and of the saturation limits of the mixtures. (10 references).—M. D. J. B.

Resurrection of a Moulding Machine. "Jacques." (*Found. Trade J.*, 1956, **101**, Oct. 25, 475–477). The adaptation of a 60-year-old moulding machine to the CO_2 process is described.

The Continuous Casting of Iron. A. Wittmoser. (*Giesserei*, 1956, **43**, Aug. 30, 473–485). The chill casting of iron is first considered in general terms. A particular instance of chill casting is continuous casting. The early work on continuous casting of iron is traced historically. The development of this process at Gelsenkirchen is described in detail, from the first experiments to the installation of a production plant. The position of continuous casting is reviewed.—R. J. W.

On the Question of the Importance of the Compression Pressure in High pressure Die-casting. F. Richter. (*Giesserei*, 1956, **43**, Aug. 30, 540–547). The high-pressure die-casting process is described and the wear of dies considered. This is affected by the compression pressure and the inflow speed. The formation of stresses and subsequent hot-cracks can be reduced by preheating the dies. The influence of reducing the pressure and of venting the dies on the quality of the castings is described.—R. J. W.

Foundry Mould Surfaces: A Test for the Depth of Skin Dryness. H. M. Walter. (*Iron Steel*, 1956, **29**, Oct., 485–486). The author describes a simple method of estimating the depth of skin dryness in sand moulds. It makes use of the fact that the electrical resistance of the sand increases with decreasing moisture content, and the apparatus required consists of an Avometer and two electrode pins.—G. F.

Silicate Solution as a Binder for the Production of Large Cores. W. Schmidt and W. Philipp. (*Giesserei*, 1956, **43**, Aug. 30, 592–593). The use of solutions of alkali silicates for use as air-hardening core-binders is described. The advantages of the solidification method are given and the compound method for producing loose sand cores described. This short article is concluded by some considerations of the economics of the process.—R. J. W.

Manufacture of a Marking Plate by the Cement-Sand Moulding Process. E. Kuschke. (*Giesserei*, 1956, **43**, Aug. 30, 593–596). A factual description of the manufacturing process. The moulding equipment, the cement–sand mixture, the construction of the core ball, and the top and bottom moulds are described separately. Finally a description is given of the runners, assembly, loading, and the casting processes.

The Progress of Special Irons and their Applications in Mineral Industry. G. Henon. (*Rev. Gén. Méc.*, 1956, **40**, Dec., 407–413). Examples of the application of new cast iron alloys are described. A nickel-chrome martensitic white iron (Ni-Hard) is shown to have a resistance to abrasion superior to manganese steel for the casing of ball mills for crushing ore. A nickel–copper–chrome austenitic grey iron (Ni-Resist) is shown to have excellent resistance against corrosion. New irons for use at high temperature are also considered.—B. G. B.

Nodular Iron in Switchgear. F. E. Florschutz. (*Mech. Eng.*, 1956, **78**, Apr., 327–328).

Ductile Cast Iron Introduced in Large Valve Body. (*INCO Mag.*, 1956, **26**, Oct. 25). An hydraulically-operated 16 in. plunger-type surge valve developing 3000 psi is described.

Planning for Heat Treating in Malleable Iron Foundries. (*Modern Castings Special Report No.* 20, 1957, Feb. 39–54).

Chemical analysis, melting practice, casting size and shape, atmosphere, casting surface and factors affecting annealing (tabulated) are briefly reviewed. Selecting proper heat treating equipment is then considered under batch and continuous types, reheat furnaces, choice of fuel, choice of alloy, maintenance and handling equipment. Selecting controls is next discussed, thermocouples being tabulated and atmosphere control systems reviewed. Economics are then briefly considered and costs indicated.

Steel Castings for Shipbuilding and Marine Engineering. (*Brit. Steelfound. Assoc.*, pamphlet ,1957, pp. 16). An illustrated review.

The Prospect for Precision Steel Castings in Aircraft. (*Precision Met. Mold.*, 1956, **14,** Nov., 48–50, 86, 87). A report based on U.S. Dept. of Commerce *PB*, 121148.

Liquid Shrinkage. Problems of Compensation in Steel Castings. E. Longden. (*Iron Steel*, 1957, **30,** Apr., 147–148; May, 173–178; Standardization of gating and feeding methods, so far as this is possible, is attempted. The influence of design is discussed in some detail and insulating and exothermic compositions and modes of application are summarized. Group control charts for pressure cylinders are shown and recommendations on gating and feeding of castings up to 20 t are made with examples. Mould assembly is described and points to be taken care of are pointed out.

Mould Mixtures Based on Carbonaceous Materials. V. A. Ul'yanov. (*Liteinoe Proizvodstvo*, 1956, (1), 25–26). [In Russian]. The preparation and properties of mould mixtures containing 82–100% of carbonaceous material (graphite, coke, anthracite) are described. The advantages of such mixtures in casting steel or iron are outlined.—S. K.

Modifications of Vertical-Gating Principles. K. H. Grube, R. M. Lang, and J. G. Kura. (*Trans. Amer. Found. Soc.*, 1956, **64,** 54–61). Step gates were found to cause no increase in turbulence but to produce undesirable thermal gradients. Change of gating ratio to use smaller runners caused only small increases in turbulence. Screens were no more effective than runner extensions to prevent entrance of dirt and a core placed opposite the web in the improved system did not increase turbulence. The water-analogy technique using cinematography of transparent model moulds was used.

Knock Off Risers Shrink Foundry Costs. D. S. Fulton. (*Canad. Metals*, 1957, **20,** Feb. 54–55). Use of exothermics gives risers with narrow necks that can be broken off with a 10-lb hammer.

The Carbon Dioxide Process of Mould and Core Production. G. E. Parramore. (*Foundry Trade J.*, 1957, **102,** Mar. 14, 325–331; Mar. 21, 361–365). An illustrated account is given of the origin, development and uses of the CO_2 process. Coremaking, gassing and surface finish and sand reclamation, gas supply, storage and economic factors are discussed in the second part.

Breakdown of CO_2 Cores. F. Le Serve and H. D. Segrove (*Foundry Trade J.*, 1957, **102,** Apr. 4, 409–411). Difficulty is encountered at 900–1100° C, mainly in copper-base alloy founding.

New Technology for Making Large Moulds. A. I. Goloshchapov. (*Liteinoe Priozvodstvo*, 1956, (1), January 1–3). [In Russian]. After describing the methods previously used for preparing large castings (e.g. machine-tool stands) a new technique for making large moulds is outlined. In this each plane is prepared separately, the mould being made up of superimposed planes.—S. K.

How to Cut the Cost of Your Large Sand Castings. (*Precision Met. Mold.*, 1956, **14,** Dec., 40–41). Shell moulding, mainly of bronze, is briefly considered.

Machining Stock Almost Eliminated with a Shell Core in a Sand Mould. (*Precision Met. Mold.*, 1957, **15,** Mar., 53–54). Close tolerance stainless castings on large cores were produced by the use of resin-bonded cores made in two parts and prevented from warping by a special press. The process replaced green sand moulding.

Internal Stresses in Castings in the Plastic-State Range of the Metal. L. S. Konstantinov. (*Liteinoe Proizvodstvo*, 1956, (1), 17–22). [In Russian]. In this article some theories of stress production in castings are critically examined and some original contributions, with special reference to the plastic range, are made. After a brief introduction to plastic deformation theory the mechanism by which stresses arise in plastic castings under various conditions and the influence of various factors (notably rate of cooling and geometrical shape of the casting) are discussed. In conclusion some applications of the foregoing data to the explanation of practical effects are considered, including the formation of porosity in the central cross-sectional region.—S. K.

VACUUM METALLURGY

Vacuum Technique in Metallurgy. A. Szulyovszky. (*Kohaszati Lapok*, 1956, **11,** (10) 456–464). The author refers briefly to the effect of vacuum on metallurgical processes. Afterwards he comments on the various vacuum pump systems and the construction and heating of the electric resistance, induction and arc vacuum furnaces. Finally he describes the following metallurgical processes under vacuum: (1) heating, (2) degassing, (3) sintering, (4) melting, (5) distillation and sublimation, (6) reduction of metal oxides and (7) metal coating.—P. K.

Vacuum Metallurgy. (*Mech. World*, 1956, **136,** Sept., 394–397). The advantages of vacuum metallurgy are discussed with particular reference to Ti, Be, and Zr. Details are given of a 56 lb vacuum melting and pouring unit fitted with a high speed vapour booster pump backed by an air ballast mechanical pump.—D. H.

Vacuum Treatment of Liquid Metal. A. M. Samarin, L. M. Novik, N. I. Goncharenko, and A. F. Tregubenko. (*Stal'*, 1956, (8), 700–707). [In Russian]. Installations for subjecting liquid steel to low pressures tested at the Enakievsk " Dneiprospetsstal' " and " Serp i Molot " works are illustrated and details for the first two are given. At the first, Bessemer rimming steel was treated, and data are given showing the favourable influence of the treatment on the O_2 and N_2 contents, the homogeneity of the ingots and rolled products and the mechanical properties are given. At the " Dneiprospetsstal' " works the method was advantageously applied to transformer, ball-bearing and chromium-nickel structural steels and is also being tried with heat resisting steels.—S. K.

Vacuum Melting and Annealing. R. Giler. (*Metal Treating*, 1957, **8,** Mar.-Apr., 14–16, 60). Vacuum equipment and types of furnaces are briefly described.

Melting Metals in Vacuum-arc Furnaces. W. J. Kroll. (*Metal Treatment and Drop Forging*, 1957, **24,** Apr., 162–168). Ti and Zr are mainly considered.

REHEATING FURNACES AND SOAKING PITS

Reheating of Steel Without Scale. A. G. Robiette. (*Iron Coal Trades Rev.*, 1957, **174,** Apr. 19, 903–910). Types of furnaces developed for non-scale heating systems are reviewed and the utilization of protective atmospheres. Uses of the processes are discussed and economic aspects of scale prevention are given. Oxygen combustion is considered and a section on alloy steels, where decarburization may also occur, is added.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

How to Select the Proper Heat Treating Equipment. C. F. Burling. (*Metal Treating*, 1957, **8,** Mar.-Apr., 2–4, 21). Number and type of furnaces, continuous or batch, and special handling problems are briefly considered.

Furnaces and Automatic Equipment. T. MacP. Lees. (*Inst. Vit. Enamel. Bull.*, 1957, **7,** Jan., 33–38). Furnaces, especially continuous furnaces, and their control equipment are briefly described and fuel costs compared for electricity, gas and oil. Box furnaces are mentioned and automation of pickling, enamel application and dryers are reviewed.

Continuous Heat Treating Boosts Output, Saves Floor Space. (*Iron Age*, 1957, **179,** Mar. 28, 122). A gas-fired controlled-atmosphere shaker hearth furnace is described, treating 25,000 lb of small screws weekly at 1700° F.

Influence of Various Elements on the Graphitisation of High-Carbon Tool Steel. K. Kusaka. (*Tetsu to Hagane*, 1956, **42,** Mar., 374–376). [In Japanese]. The effects of aluminium and silicon on the graphitization of austenitized and cold-drawn steels heat-treated under varying conditions are traced. The effects of Cr, As, Sb, Sn, W, Mo, V, and Te are also indicated.

On the Distortion of Ball Bearing Steel. A. Adachi and Z-i. Morita. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1956, **6,** Mar., 133–139). Effects of heat-treatment are examined. Thermal

stress and austenite transformation are responsible for distortions and the former can be avoided.

Metallurgical Qualification of High Carbon Steel. H. A. Springer. (*Wire and Wire Products*, 1956, **31**, Aug., 882–884, 941). Analysis and control and heat-treatment record systems are outlined.

Heat Treatment and Properties of Cr–Mo Steels for Hot Dies. S. Koshiba. (*Tetsu to Hagane*, 1956, **42**, Mar., 246–247). [In Japanese]. Data are given on deformation amounts and quenching temperature for six steels of given analyses.—K. E. J.

Control Measures for the Heat-Treatment of High-Carbon Rods and Wire. N. D. Montgomery. (*Wire and Wire Products*, 1956, **31**, Nov., 1325–1326, 1390–1391). Pittsburgh Steel Co. practice is outlined.

Patenting Wire by Means of Gas Furnaces. H. Anders. (*Wire Prod.*, 1956, **5**, July, 15, 17–18).

Quality Control Through Heat Treatment. J. J. Warga. (*Metal Progress*, 1956, **70**, Nov., 78–80). The steps necessary to ensure the production of consistently high quality heat-treated components for aircraft are discussed.—B. G. B.

On the Nature of Surface Zones Formed During the Diffusion of Chromium into Iron. G. N. Dubinin. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (6), 1234–1350). [In Russian]. The structure of the layer formed during chromizing of iron (0·03% C) was investigated using microscopical, X-ray, spectral analysis, and microhardness techniques. In addition to the "line" of phase transformation another linear "separating zone" situated nearer to the external zone of specimens was found. Causes of the formation of the separating zone and its structure are discussed.—V. G.

Studies on the Characteristics of Chromising. V. S. Ueda. (*Tetsu to Hagane*, 1956, **42**, Mar., 361–362). [In Japanese]. The vacuum testing apparatus is described, and results are given for the temperature variation of the diffusion coefficient for chromium in iron.—K. E. J.

Reactions Between Chromium and Iron Chlorides at High Temperatures. N. G. Klyuchnikov. (*Zhur. Priklad. Khim.*, 1956, **29**, (2), 161–165). [In Russian]. It was shown that during thermal chromizing in the presence of chromium chlorides two reactions take place: (1) exchange reaction—

$$CrCl_2 + Fe = FeCl_2 + Cr$$

and (2) direct reduction of chromium from its chloride in which atomic hydrogen dissolved in the surface layer of iron participates:

$$CrCl_2 + 2[H] = Cr + 2HCl$$

Changes in dimensions of specimens during chromizing depend on the reaction by which chromium is deposited without substitution of iron.—V. G.

Studies on the Gas Carburisation. On the Erosion Resistance in Various Atmospheres of Stainless Steel, Heat-resisting Steel and Electric Heating Wire. N. Komuro. (*Tetsu to Hagane*, 1956, **42**, Mar., 353–355). [In Japanese]. Tests were made on steels of different type and composition (given). Results show the increase in weight, erosion depth, and types of diffusion found when the steels were oxidized, carburized, nitrided and carbonitrided for 40 hours at 900° C. The relationship between time and change of weight is also given, for carburizing at 1000° C.—K. E. J.

Change of Dimension of Case-hardening Steel Cementation and Heat-treatment. M. Yamaki. (*Tetsu to Hagane*, 1956, **42**, Mar., 388–389). [In Japanese]. Tests are reported on Ni–Cr and Cr–Mo steels (compositions given).—K. E. J.

The Dimension Change of Case-Hardening Steels Resulting from Carburising and Heat Treatment. M. Yamaki. (*Tetsu to Hagane*, 1956, **42**, Aug., 656–663). [In Japanese]. No appreciable difference was found between low-carbon Cr–Mo and Ni–Cr steels for dimensional changes resulting from carburizing and heat treatment, but the fibre structure caused by rolling had a great effect on both; the mechanism is explicable by heating and cooling transformation curves. Methods of carburizing and heat treatment are suggested.—K. E. J.

Study on the Case-hardening of Stainless Steels. I. Induction Hardening of 13% Cr Steel and its Application. T. Takase. (*Tetsu to Hagane*, 1956, **42**, Mar., 387–388). [In Japanese]. Results are given for tests of valves operating with steam at 400–460° C and 30 kg/cm².—K. E. J.

Experiences and Directions for the Surface-hardening of Cast Materials. G. Seulen and O. Fischer. (*Giesserei*, 1956, **43**, Aug. 30, 558–565). The various methods of carrying out the surface hardening process are described. The most important are induction hardening and flame hardening. The cast materials suitable for surface hardening are described under the following headings: cast steel, cast iron, and malleable cast iron.—R. J. W.

Automatic Hard Surfacing with Alloy-containing Fluxes. W. G. McFarlane. (*Canad. Metals*, 1956, **19**, Nov., 24). A brief description of an automatic hard-surfacing process using the submerged arc technique with mild steel welding wire and special fluxes which supply the alloying elements is given.—B. G. B.

Mechanized Selective Hardening of Yoke-type Axle Shafts. K. M. Yeager. (*Steel Processing*, 1956, **42**, Nov., 645–646). A rotary conveyor mechanism is described together with combustion set-up and temperature control of the lead bath. A rate of 120 pieces per hour is claimed, where a 3-in. portion of the yoke end is heat treated.—A. H. M.

Study on Timken 16-25-6 Type Heat-Resisting Alloy. I. Influences of Solution Treatment and of Nitrogen on High-Temperature Age-Hardening. Y. Imai and K. Tanosaki. (*Tetsu to Hagane*, 1956, **42**, Aug., 663–668). [In Japanese]. The effects of solution treatment in the range 1000–1250° C and nitrogen contents of 0·04–0·16% are reported. With higher nitrogen contents, higher temperatures of solution treatment are needed to obtain complete high-temperature age-hardening.—K. E. J.

Dual Frequencies Put New Life in Heat Treating Line. W. H. Lenz. (*Iron Age*, 1956, **178**, Sept. 6, 96–98). An instance is cited of how a shop heat-treating bar stock for hardening and tempering has introduced 2 frequencies for induction heating. 180 c.p.s. coils are used for preheating, 9600 c.p.s. for hardening. Increased production and other advantages are reported.—D. L. C. P.

Metallurgical Study on Induction Surface Hardening. V. Effects of Tempering and Martempering on Induction Hardened Bearing Steels. Y. Mitani. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, July, 350–353). [In Japanese]. Since martempering is suitable for eliminating residual stress, and hence prolonging the pitting time and life of ball bearings, a comparison was made of martempering applied to steels hardened by the induction method and tempered at low temperature.—K. E. J.

Specifications for Induction Heat Treatment Installations. C. Di Pieri. (*Ingegneria Mecc.*, 1956, **5**, March, 5–14). [In Italian]. This article reviews the basic principles of induction heating for surface hardening, welding, and forging. The technical and economic advantages of the process are discussed.—M. D. J. B.

Economic Aspects of the Heat Treatment of Good Electric Conducting Materials by Radio-Frequency Generators. G. Giacometti. (*Ingegneria Mecc.*, 1956, **5**, Mar., 31–37). [In Italian]. The author discusses briefly the advantages of radio-frequency heating compared with conventional methods for the treatment of metals and alloys. The apparatus and its technical and operational characteristics are described and the economics of the process discussed.—M. D. J. B.

Siliconising of Iron. M. Someno. (*Tetsu to Hagane*, 1956, **42**, Mar., 360–361). [In Japanese]. Data are presented for siliconizing of iron through the reduction of $SiCl_4$ by hydrogen, and explanations are given of the mechanism of the reaction.

Diffusion Siliconising. N. S. Gorbunov and A. S. Akopdzhanyan. (*Zhur. Priklad. Khim.*, 1956, **29**, (5), 655–659). [In Russian]. It is proposed to modify diffusion siliconizing of iron so that instead of using a current of chlorine the working volume of the furnace is initially filled with chlorine at room temperature. The dependence of the silicon diffusion layer on temperature and duration of the treatment as well as on the carbon content of the metal was demonstrated. The weight and dimensions of a specimen change during the siliconizing process.—V. G.

Properties of Silicon Coatings Produced by Diffusion. A. S. Akopdzhanyan and N. S. Gorbunov. (*Zhur. Priklad. Khim.*, 1956, **29**, (5), 659–663). [In Russian]. It was established that siliconized iron is resistant to the action of 10% sulphuric, phosphoric, and hydrochloric acids, 3% sodium chloride, 5% calcium chloride, and 5% sodium sulphate. Siliconized specimens were found to be resistant to the oxidizing action of air at elevated temperatures (up to 800° C). Hardness and wear tests of siliconized specimens indicated that they were considerably more resistant than the initial iron specimens.

Metallurgical Aspects in the Design and Operation of a New Continuous Annealing Line. A. J. Mohri. (*Blast Furn. Steel Plant*, 1956, **44**, Sept., 1043–1047; Oct., 1175–1178). Investigations by means of a thermocouple with recorder on test

strips are reported and recrystallization temperature, effective soaking time, and maximum annealing temperature were determined. Six steels were examined and findings are shown graphically. Factors influencing the hardness of sheet steel are considered and practical methods of controlling the hardness on a continuous annealing line are discussed in relation to these factors.

Influence of Local Rapid Heating and Cooling Treatment Aiming at Strain Removal in Mild and High Strength Weldable Steel. T. Mimino. (*Tetsu to Hagane*, 1956, **42**, Mar., 330–331). [In Japanese]. V-notch Charpy impact values are given for distances up to 100 mm from central portions rapidly heated and either air- or water-cooled.—K. E. J.

Normalizing Effect on Heavy Thickness High-tensile Steel. K. Miyano. (*Tetsu to Hagane*, 1956, **42**, Mar., 332–333). [In Japanese]. Tensile properties and transition temperature data are given for as-rolled and normalized plates of thicknesses varying from 30 to 50 mm (compositions given).—K. E. J.

Electric Salt-Bath Furnaces. Greater Efficiency than Conventional Furnaces. (*Corrosion Techn.*, 1957, **4**, Apr., 118–119). A review is presented in general terms of the principle, design, operation and uses of these furnaces, with a note on automation. Salts used for various purposes are mentioned and electrode design and pot life referred to.

Method of Checking the Fluidity of Fused Media for the Heat Treatment of Steels in Fused Salts and Alkalies. A. I. Zot'ev and Yu. A. Zot'ev. (*Zavodskaya Laboratoriya*, 1956, **22**, (6) 695–697). [In Russian]. Fluidity determinations on working fused-salt or alkali heat-treatment baths are effected by timing the filling by the medium of a standard chamber through a calibrated aperture. The apparatus and procedure are described.—S. K.

Continuous Electric Furnaces. (*Wild Barfield Heat-Treatment. J.*, 1956, **5**, June, 10–13). Some brief notes are given on electrical resistance furnaces for continuous heat-treatment.

Industrial Furnace with Portable Cover and Fixed Hearth. (*Indust. Gas*, 1956, **19**, Aug., 360–362, 366). Details are given of a versatile gas fired furnace for stress relieving, normalizing and annealing. It consists essentially of a base containing a working hearth and a portable refractory lined hood forming the working chamber.—D. H.

Selection and Application of Furnace Atmospheres for Quality Control. O. E. Cullen. (*Indust. Heating*, 1957, **24**, Mar., 465, 466, 468, 470, 472, 474). The use of dewpoint control to obtain various operations, (carburizing, caronitriding, cleaning or hardening), from a single type of atmosphere is described.

The Application of Walking Beam Furnaces. (*Wild-Barfield Heat Treatment J.*, 1956, **5**, Sept., 10–14). Some details are given of installations for the continuous heat treatment of heavy or bulky components.—D. H.

Tunnel Annealing Furnace Speeds Stainless Parts Production. P. M. Unterweiser. (*Iron Age*, 1956, **178**, Dec. 6., 128–129). Brief details are given of a new type of tunnel annealing furnace by Selas Corp., heated by radiant burners with a short heating cycle, and easily handled by one operator. The furnace has greatly speeded up the in-process annealing of certain stainless steel parts.—G. F.

The Carbon Arc Image Furnace. T. P. Davis. (*Indust. Heating*, 1957, **24**, Mar., 496, 498, 500, 502, 504). An optical system for reflecting or refracting radiation to the work is required, and measurement and control of radiation are reviewed.

Some Thoughts on Spring Heat-Treatment and Finishing. E. Mitchell. (*Wild-Barfield Heat Treatment J.*, 1956, **5**, Sept., 2–7). The metallurgical aspects of the heat treatment of springs are discussed and the types of equipment briefly described.—D. H.

Hardening High-Speed Steel. Efco-Lindberg "L-Type" Furnace. (*Iron Steel*, 1957, **30**, May, 178). A brief account of the furnace, the sizes available, and their outputs is given. Advantages are enumerated.

Control Flatness of High Strength PH. Sheet. L. E. Laux. (*Iron Age*, 1956, **178**, Nov. 29, 84–86). The author discusses the difficulty of avoiding distortion when heat-treating precipitation-hardening (PH) steel sheet to maximum strength levels. He describes two methods of controlling distortion, one involving several stretch-flattening operations and the other a weighted rig of plywood and metal channel.—G. F.

Air Injection. A New Carburizing Control Technique in Zoned Atmosphere Furnace Operation. H. C. Harris. (*Steel Processing*, 1957, **43**, Mar., 158–162). Steels for case-hardened gears were used and an optimum surface C content of 0·80% was produced while providing sufficient case depth. Continuous lines are described with 5-zone furnaces. Quenching and atmosphere control, with analyses, are discussed.

Case Hardening Steel Parts. Heating Salt Baths. T. H. Pardoe. (*Gas World, Industrial and Commercial Gas Supplement*, 1957, **35**, Feb. 16, 48). An account of salt bath practice in the production and maintenance of Public Service Vehicles is given.

The Metallographic View. H. E. Boyer. (*Steel Processing*, 1956, **42**, Feb., 100–101). XIX. **Metallography of Carburized Cases.** An elementary discussion with illustrations of carburized metal, natural size and ×50. XX. **Metallography of Carburized Cases before Hardening.** (Mar., 154, 167). Four micrographs of the zones in XIX at higher magnifications are given. XXI, **Metallography of Carburized Cases,** (Apr., 217–218, 229). The effects of heat treatment are mentioned. A quenched specimen is illustrated, × 50. XXII, (May, 279, 289). Rapidly cooled specimens are illustrated at × 500. XXIII, **Retained Austenite,** (June, 331–332). Sections are shown before and after low-temperature transformation. XXIV, **Metallography of Carburized Cases, Refinement Afforded by Double Treatment.** (July, 396, 414). XXV, **Surface Decarburization—Partial and Total.** (Aug., 462–463). The phenomenon and its effects are described and illustrated. XXVI, **Hardness of Microconstituents of Steels.** (Sept., 516, 534). Ferrite, pearlite and cementite are illustrated in carburized unhardened stock. XXVII, **Nitriding for Case Hardening.** (Oct., 573, 589), XXVIII, **Metallography of Nitrided Cases.** Nov., 639–640). Hardness values are given. XXIX, **Nitriding the Lower Alloy Steels.** (Dec., 700–701, 708). Microstructures and the relation of hardness to depth are shown. XXX. **Nitriding the Higher Alloy Steels.** (1957, **43**, Jan., 36–37, 45). Depth-hardness patterns and structures for a hot-work and a stainless steel are shown. XXXI. **Structure and Hardness of Liquid Nitrided Cases.** (Feb., 84, 105–106). High-speed, aluminium-bearing nitriding grade and 410 stainless are illustrated and hardening curves shown. XXXII. **Metallographic Characteristics of Cyanided and Carbonitrided Cases.** (Mar., 142–143, 170). Structures are shown and the relation of hardness to depth is indicated.

Nitriding Stainless Steels Costs Less in a Salt Bath. H. A. Johnson. (*Mat. Methods*, 1956, **44**, Nov., 113). Case depths and hardness gradients are reported.

Annealing Furnaces for Cold-Rolled Steel Strip. R. Grmela. (*Hutník*, 1956, **6**, (9), 268–271). [In Czech]. The performances, running and investment costs of continuous and tubular furnaces are compared. The conventional tubular furnaces are considered to be superior to the continuous types particularly if the sheet is to be annealed rather than normalized. Replacement of tubular furnaces by continuous ones is not advised, except if normalized strip is being produced. The latter is however unsuitable for general deep-drawing processes.

Design, Performance, and Operational Results of a New Wide-Strip Continuous Annealing Furnace. V. Seul and J. Billigmann. (*Stahl u. Eisen*, 1957, 77, March 21, 309–323). The first wide-strip continuous annealing furnace in Europe was brought into operation by Stahlund Walzwerke Rasselstein/Andernach A.G., Germany, in 1955. Design, performance, operational results, electric drives, economics, etc., are discussed in detail. Strip up to 1000 mm wide and 0·2–0·5 mm thick can be annealed. The speed of the strip is about 65 m per min. Gas consumption is equivalent to 120,000 kg.cal. per ton of strip steel, 25 m^3 (NTP) of protective gas, 12 kWh. of power and 2 m^3 of cooling water per ton of steel are also used. Micrographs and hardness charts illustrate the superiority of the annealing process in the continuous furnace compared with a bell-type furnace on a variety of steels.—T. G.

Speed-Up for Bright Stainless Tubing. (*Steel*, 1957, **140**. Apr. 1, 100). A conveyorized muffle-type annealing furnace is briefly described handling tubes up to 4 in. dia.

Hot Oil Quenching. L. W. Kalinowski. (*Metal Treating*, 1957, **8**, Mar.-Apr. 10–12, 54–56, 59). Full and modified marquenching, process selection and comparison with salt baths, furnace equipment, parts treated, oil qualities and tests necessary are discussed.

How Measurements Lead to Effective Quenching. V. Paschkis and G. Stolz, jun. (*Iron Age*, 1956, **178**, Nov. 22, 95–97). The authors describe how accurate temperature measurements, continuously recording temperature changes of parts in a quench bath, can make heat treatment easier and

more scientific. The effectiveness of still water and brine quenches, and of agitation in quenching, are discussed.—G. F.

The Tempering of Steel. E. D. Hyam. (*Abstracts of Dissertations, University of Cambridge*, 1953–1954, 209–210). Electron microscopical studies are reported. The amount and degree of dispersion of the carbide phase was found to vary with time and temperature of tempering in four C and one alloy steel.

FORGING, STAMPING, DRAWING, AND PRESSING

Hot Forged Parts. J. L. Everhart. (*Mat. Methods*, 1957, **45,** Mar., 135–153). (Materials and Methods Manual No. 136). A review of materials and processes, with an account of uses, and choice of suitable compositions and methods. Non-ferrous metals are included, brass, Al and Ti.

Better Forgings. Proper Testing is Essential for Improved Products. I. E. Suchoversky. (*Steel Processing*, 1957, **43,** Mar., 127–134). Recommendations for testing are made, especially on the location of test pieces in large forgings.

Properties of Large Steel Forgings. E. A. Loria. (*Steel Processing*, 1957, **43,** Apr., 193–198). Effects of heterogeneities on mechanical properties are discussed. Transverse reduction of area (RAT) and longitudinal reduction of area (RAL) and their ratio are considered and relationships shown. Dendritic structure, banding and inclusions are referred to, with their effects and avoidance. (12 references).

Use of Radioactive Tracers in the Investigation of Wear of Drop-Forging Dies. D. B. Smith, H. Southan, and H. A. Whiteley. (*Metal Treatment and Drop Forging*, 1957, **24,** Apr., 131–136). A study in which a small piece of radioactive steel was inserted into the floor of a die at a point where there was a good flow of metal during forging is reported. A Ni Cr Mo No. 5 die steel was activated in a pile in the form of a cylinder. 0·499 in. dia. by 1 in. long and 25·1283 g wt. Studies on scale are also reported. It was found that wear occurs by rubbing away of particles, but whether by the steel being forged or by the scale is not clear. Transfer occurs from die to forging and back to the die and wear starts with the first forging made. The scale is always active and activity rises steadily in the early stages.

Automatic Servo-control Applied to Hydraulic and Electro-hydraulic Systems and its Application to Large Presses. C. R. Himmler. (*Silicates Indust.*, 1957, **22,** Mar., 131–140). Motors, pumps and force amplifiers and their control and application to presses are described.

Paint Parts First, Machine Later. A. A. Janis. (*Iron Age*, 1957, **179,** April 18, 114–115). Epoxy coatings can be used before stamping or forming, and protect surfaces from corrosion or mechanical damage. Polished parts are cleaned in alkaline baths and sprayed with resin and baked.

The Utilization of Strip Material in Press work. (*Mech. World.* 1956, **136,** July, 326–327). Illustrations are given of the economies arising in strip material by suitably arranging the blank in the strip irrespective of grain direction.—D. H.

Stripping Pressures. A Simple Shop Method for Their Determination. F. Strasser. (*Steel Processing*, 1957, **43,** Mar., 135). A brief account of the factors involved is given with average values for stamps and punches.

Fabricating Mechanical Steel Tubing. (*Mat. Methods*, 1956, **44,** Nov., 124–127). Bending, expanding and flanging, swaging and upsetting are outlined.

Drawn Steel Has Unique Properties. (*Canad. Metals*, 1957, **20,** Mar., 22). Free-machining bar steel hot-drawn for special properties gives Rockwell C of 30, tensile strength of 140000 psi and yield strength 125000 psi.

New Apparatus for Measuring Force in the Drawing of Metal. V. G. Grosval'd and A. G. Smirnova. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 357–359). [In Russian]. A multiple-coil inductive differential transducer is used in the device described. This was developed for measuring the force in wire drawing, but is applicable for the same purpose in other metal-working processes such as rolling or deep drawing.—S. K.

Treatment of Surfaces by the Phosphation Process before Cold Deformation. M. Lefèvre. (*Rev. Gén. Méc.*, 1956, **40,** Dec., 403–406). Phosphating processes for treating the surface of steel to increase the ease of cold drawing are described. Mild and stainless type steels are considered. The phosphate coating on the steel surfaces increases the retention of a lubricant on the steel and enables a considerable increase in output from existing plant to be obtained.—B. G. B.

Industrial Diamonds in the Wire Mill, L. A. Zucker. (*Wire and Wire Prod.*, 1956, **31,** Dec., 1443–1445, 1498–1506). Following an explanation of factors which determine the cost of industrial diamonds and boart, their uses as abrasives and tools in the wire mill are explained. Costs of using silicon and boron carbide powders for grinding and polishing dies are compared with those of diamond powder, and prospects of future supply in the U.S.A. are considered.—J. G. W.

The Work-Hardening Behaviour of Round Wire During Various Types of Working. II.—Effect of Drawing on the Strength of the Wire in Subsequent Flat Rolling. W. Dahl and W. Lueg. (*Stahl u. Eisen*, 1957, **77,** March 21, 334–340). Cf. *ibid.*, 1956, **76,** 1099. Wires drawn by processes described earlier were flat-rolled or pressed. It was found that work-hardening of steel 1 is smaller when the reduction in the previous drawing was heavier. For steel 2, U.T.S. is reduced by pressing or flat rolling if the previous reduction was greater than 25%. This reduction increases with increase in the previous amount of working. This is attributed to elimination of residual stresses imposed during previous operations.

The Extrusion of Steel with Glass Lubricant. G. Leclerc. (*Rev. Gén. Mécan.* 1956, **40,** Nov., 369–374; Dec., 423–428). The principle of the Ugine-Séjournet process is described. The design of equipment necessary is discussed and plant data, showing the influence of pressure on the extrusion operation are given. Examples of the wide application of the technique are reported.—B. G. B.

Study of Die Wear by Means of Radio-activated Surfaces. B. J. Jaoul. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** July, 1135–1139). The use of radioactive isotopes in the general study of wear is briefly explained. The application of this technique to the investigation of die face wear during the hot extrusion of steel is discussed.—D. H.

ROLLING-MILL PRACTICE

Effect of a Finishing Pass and of Ageing on the Yield Point of Strip Steel of Deep-Drawing Quality. F. Fischer, M. Nacken, and V. Seul. (*Stahl u. Eisen*, 1957, **77,** March 21, 340–346). The authors investigated the conditions for a finishing pass, i.e. degree of reduction, roll dia. ,and lubricant, at which strip steel of deep-drawing quality will not show stretcher strains in deep drawing. The amount of reduction, however, is limited by ageing effects. The authors explain, in terms of dislocation theory, how stretcher strains can be avoided. If, by metallurgical processes, locking of dislocations by foreign atoms could be eliminated, the finishing pass, i.e. the yield-point shift, would no longer be necessary.—T. G.

Lathe Boosts Roll Turning. (*Steel*, 1957, **140,** Mar. 4, 99–100). A lathe taking workpieces up to 63 in. dia. and weighing 90 t is described.

Determination of a Laboratory Index of the Resistance to Wear of Textolite for Rolling-Mill Bearings. I. M. Nikberg, E. S. Shlyakhovetskiĭ, I. I. Abara, and N. V. Pashutin. (*Zavodskaya Laboratoriya*, 1956, **22,** (6), 731–733). [In Russian]. Improvements in laboratory wear tests on different batches of textolite are described, the results obtained being compared with those of production-scale tests on rolling-mill bearings. Though qualitative agreement was found, the relevance of the laboratory index is not yet established.—S. K.

Three High Roughing Down Rolls with Variably Inclined Feed Table. M. Bonaud. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13,** 2413–2416). A short description of this type of roughing roll is given. Recent changes in design have improved the output of such mills considerably. A line drawing of the roughing roll is given.—B. G. B.

The Thirty-Four Day Hustle. (*Anvil*, 1957, **4,** Spring, 4–7). A brief illustrated account of the reconstruction of the Templeborough Rod Mill.

Rationalization of Roll-Pass Design of a 330 Mill. V. P. Sazonenko and V. V. Ostapenko. (*Stal'*, 1956, (8), 716–721). [In Russian]. Details are given of roll-pass designs and rolling procedures the use of which has enabled 26 different section-sizes to be rolled from the same billet (60 × 60 mm) in six passes (including the roughing pass).—S. K.

Note on the Shape of H-Girders. J. Courtheoux. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13,** 2417–2423). The dimensions and weights of thin girders used in France and America are discussed and tabulated.—B. G. B.

Production of New Types of Tram Rails. I. I. Kuchko, M. G. Serkin and I. B. Rapoport. (*Stal'*, 1956, (8), 708–716). [In Russian]. Recent changes in the rolling of tram rails to keep pace with new rail-designs are described, with special emphasis on roll-pass design.—S. K.

Hand Rolling, Good Scheduling, Boost Mill's Efficiency. W. G. Patton. (*Iron Age*, 1956, **178,** Dec. 27, 62–64). A mill for short-run stainless items, largely hand-operated, is described with details of the design and operation as planned to keep down the costs. It can roll 27 items with 5 roll changes.

Steel Rolling Mill Opened at Kwinana, Western Australia. (*Commonwealth Eng.*, 1956, **44,** Dec. 1, 141–142). **The New B.H.P. Steel Mill.** (*Australasian Eng.*, 1957, **49,** Jan. 7, 57–59).

Rolling with the Hot Planetary Mill. H. M. Walter. (*Iron Steel*, 1957, **30,** Mar., 95–100). The author surveys the flow of material in planetary mill hot-rolling, describing the results of plasticine model work on a full-scale replica of the mill. He discusses the effects on the flow pattern of work roll size, slab thickness, temperature, feeding speed, slip forwards and backwards, the angle of bite, and surface scale.—G. F.

The Effects of the Mechanical Characteristics of a Rolling Mill on the Uniformity of the Gauge of Cold-Rolled Strip. H. Grüner. (*Stahl u. Eisen*, 1957, **77,** March 21, 347–353). Gauge variations in cold rolling were studied on copper–beryllium (1·7 and 2% Be) with a pneumatic thickness-measuring recorder. Eccentric rolls affect the gauge of the strip periodically. The degree of gauge variation depends on the rigidity of the stand and on the plasticity of the material to be worked. The tests were carried out on a two-high, on a six-roll cluster, and on a twelve-roll Rohn-type mill. The author attempts to correlate uniformity of gauge and plasticity of the material with stand rigidity and eccentricity of the rolls. He finds that reduction of stand rigidity may, under certain circumstances, improve the uniformity of the gauge.—T. G.

Study of Different Continuous Rolling Trains for Billets. A. Poncelet (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1956, **13,** 2425–2445). A review is made of different methods of reducing billets in continuous mills. Numerous illustrations of the reduction per pass for the different methods are shown and discussed.—B. G. B.

Methods Called 'Statistical Control of Quality'. R. Rambach. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14,** (2), 355–366). The application of statistical principles to Quality Control is discussed with particular reference to the steel industry. Examples are given of the application to rolling mill operation.—B. G. B.

Automatic Gauge Control Mark I Production Unit Takes Over at Corby. R. B. Sims. (*Anvil*, 1957, **4,** Spring, 11). Equipment to a cold-rolling plant is noted.

Bending by Rolling of Ferrous and Non-Ferrous Plate. E. L. Tinley. (*Welding Metal Fab.*, 1956, **24,** Dec., 452–455; 1957, **25,** Jan., 24–27; Feb., 66–67). Types of machines and rolls are discussed, and operation and protection, materials, drives, roller removal and other factors are reviewed.

Installation of New Rolling Mill Completed for Kayser Ellison and Co., Sheffield. (*Wire Ind.*, 1956, **23,** Dec., 1093, 1095). A 10½ in. double duo mill, newly built by the Brightside Foundry and Eng. Co. Ltd., for the rolling of black wire, and associated furnace and wire-drawing equipment is described.—J. G. W.

Shearing and Friction Sawing. C. Emerson. (*Metalworking Prod.*, 1956, **100,** Nov. 16, 1871–1874).

New Hot Downcoiler in Production at Abbey Works. (*Anvil*, 1957, **4,** Spring, 9–10). Closed circuit TV control is included.

New Continuous Gauge. (*Iron Steel*, 1957, **30,** May, 171–172). A gamma-ray hot strip thickness recorder is described installed at a mill of United Steel Cos. Ltd.

MACHINERY FOR IRON AND STEEL PLANT

Recent Developments of Drives in Iron and Steel Works with Squirrel-Cage Motors of Special Deisgn. H. Wickler. (*Stahl u. Eisen*, 1957, **77,** March 7, 270–279). This is a very comprehensive review of the various fields of application of squirrel-cage motors of special design. This type of motor contributes to the simplification and reliability of drives in iron and steel works. The trend is towards single drive by a number of individually controlled motors.—T. G.

Compressed Air Essentials in Steel Plant Operations. (*Blast Furn. Steel Plant*, 1957, **45,** Mar., 326–328, 344). Uses are listed and the selection of compressors is considered. Air filters and discharge lines, valves, moisture traps, exhaust pipes, distribution, operation and maintenance are all briefly reviewed.

WELDING AND FLAME-CUTTING

Cold Electric-Arc Welding of Cast Iron. A. E. Asnis and Yu. V. Latash. (*Liteinoe Proizvodstvo*, 1956, (1) January, 6–8). [In Russian]. The arc welding of cast iron using various single and bi-metal electrodes and without preliminary heating of the part is considered, with special reference to the metallographic aspect.—S. K.

Get Twofold Weld Protection with New Process. (*Iron Age*, 1957, **179,** Apr. 18, 120–121). The Dual-Shield process using flux and inert gas is described. The gas is CO_2 and the flux detaches on cooling.

On the Problem of Weld-Repairs of Worn Rail Junction Pieces. J. Krajňák and J. Lustoň. (*Zváranie*, 1957, **6,** (2), 42–48). [In Slovak]. The technology of weld repairs by means of the electric arc as well as by means of the oxy-acetylene torch as developed by the authors is described. Methods of carrying out the repairs on the line while actually in service have been worked out in detail and are discussed. The savings estimated to accrue from such weld-repairs to the railways are evaluated.—P. F.

New I-Beam Profiles and U-Girders Suitable for Welding. (*Prat. Sond.*, 1956, **10,** Mar., 204–210).

Automatic Welding of Special and Low Alloy Steels in an Argon Atmosphere. R. Arnaud. (*Métaux-Corrosion-Indust.*, 1957, **32,** Jan., 38–45). A practical account of the principles of this technique is given and the influence of the intensity of the electric arc on the efficacy of welding is discussed. Examples of commercial equipment are shown and the limitations and possibilities of the technique considered.—B. G. B.

Problems of Resistance Welding Technology. E. Hörmann (*Vakuum-Techn.*, 1956, **5,** Aug., 108–109). A review is given of the papers presented at the conference held on 29th May, 1956, at the Haus der Technik, Essen. W. Brunst dealt with "Resistance Welding Technology and its Competitors"; O. Gengenbach discussed "Fixed and Portable Welding Equipment"; Verhoeven reported on the gas-butt welding process for cold work-hardened steels; W. J. Farrell lectured on "Application and Progress of Resistance Welding in Automobile and Aircraft Production; and E. Hörmann spoke on "Induction Welding and Comparisons between Gas-Butt Welding and the other Pressure Welding Processes."

The Manufacture of Electrically Resistance-Welded Steel Tube. W. E. Jones. (*Australasian Eng.*, 1957, 49, Jan. 7, 63–66). Practice at British Tube Mills (Aust.) Pty. Ltd., South Australia is described in detail.

ISCOR's Manufacture of Welding Wire. M. Eaton. (*Engineer Foundryman*, 1957, **21,** Mar., 50–55). The ore, blast-furnace process, casting and impurities, control of slag, control through burden changes, hot metal purification, O.H. practice, welding metal control, C and Mn adjustment, rimming, soaking pit practice, blooming, end-cropping, rolling, descaling and baking and lubrication are described. With discussion.

On the Production of Welding Electrodes and Iron Powder. A. Kleander. (*Zváranie*, 1957 **6,** (2), 48–54). [In Czech]. The technology of electrode production for shielded arc welding is discussed with special reference to possible improvements in the quality of iron powders used for electrode coatings. Economic aspects of iron powder production are considered.—P. F.

Advances in the Development of Titanium Oxide-Coated Welding Electrodes. C. De Rop. (*Stahl u. Eisen*, 1957, **77,** Feb. 21, 215–218). The coat of these electrodes contains 30–50% titanium oxide usually as rutile. The advantage of their use is high welding speed up to 50 cm per min with good slag cover of the bead. In spite of this the joints show excellent mechanical strength and microstructure.—T. G.

Metallography in Welding of Grey Cast Irons. I. Hrivňák. (*Zváranie*, 1957, **6,** (3), 75–77). [In Slovak]. The addition of various amounts of alloying elements and their influence

on the graphitization of grey cast irons are discussed from the point of view of the heat treatments resulting from the welding process and the quality of the welds. Welding with preheating as well as without is considered, and the phases formed in the iron during cooling are described, reference being made to the micrographs given in the paper.—P. F.

Effect of Heat-Treatment on the Mechanical Properties of Welds of Steel in Boiler and Vessel Construction. W. Hummitzsch. (*Stahl u. Eisen*, 1957, **77,** March 7, 279–290). Welds made on a variety of boiler plates with various electrodes, including coated electrodes of various types, were cold or hot worked after normalizing or stress-relieving. Hydrogen gas content, partial pressures, and equilibrium temperatures were studied as a function of the welding electrodes used. The report is illustrated by a number of photomicrographs and the results are presented in tables and graphs.—T. G.

Hydrogen Contents of Mild and Alloy Steel Weld Deposits. With Some Reference to the Effects of Hydrogen Embrittlement in Welded Joints. P. D. Blake. (*Brit. Welding J.*, 1957, **4,** Mar., 146–154). Various types of electrodes were used including those conforming to B.S. 1719. The effects of drying the electrodes just before welding are reported. Evolution of H_2 from weld metal appears to be non-continuous. Four mechanisms for embrittlement are advanced which may apply according to the conditions. A. Hot cracking due to deformation at temperatures below the bulk liquidus temperature coupled with grain boundary weakness. B. Fissuring below 500° C due to excessive H_2 concentration in the arc atmosphere and a high weld cooling rate preventing diffusion. C. Cracking in the heat-affected zone of high-tensile welded joints of the sort known as " underbead " or " hardened-zone " for which two mechanisms are possible one of which is D. Cracking occurring some hours after cooling which is diffusion-controlled. These varieties are discussed in turn. (25 references).

Take Six Steps to Better Brazing. (*Iron Age*, 1956, **178,** Nov. 29, 80–81). Correct practice in producing strong, high-quality joints by silver brazing is discussed. Attention to factors such as joint spacing, pre-brazing and post-brazing cleaning, fluxing, and jigging, can improve quality considerably and thus reduce costs.—G. F.

Investigating the Strength of Copper Brazed Joints. R. C. Grassi, I. Cornet and R. S. Berger. (*Mech. Eng.*, 1956, **78,** 630–632). The effects of brazing time, class of fit and prior grain size on the strength of brazed joints in plain carbon steel using copper and silver as braze materials were investigated. The high strength of the copper brazed joints was attributed to the greater work-hardening capacity of the copper under restraint and the alloying effect of the iron.—D. H.

Honeycombs for B-58 Arc Brazed. (*Steel*, 1957, **140,** Apr. 8, 94–95). The brazing of stainless steel honeycomb panels for delta wings in briefly described.

Brazing Stainless Steel Honeycombs. G. J. Orites. (*Steel*, 1957, **140,** Apr. 8, 92–95). Retort brazing is the most widely-used process and vacuum brazing the most promising. Alternatives (hot and cold wall vacuum, induction, electric blanket, blow torch, radiant lamp and salt bath) are mentioned.

Some Aspects of Metal Bonding. A. Hartman. (*Metalen*, 1957, **12,** Mar. 30, 98–105). Uses in structural engineering with comparison of static and fatigue strength of riveted and bonded lap joints and stiffened light alloy panels are reviewed. Testing by peeling, droplet and ultrasonic tests is discussed.

A Strain Gauge for the Measurement of Strains in Adhesive Bonds. C. B. Norris, W. L. James, and J. T. Drow. (*Amer. Soc. Test. Mat. Bulletin*, 1956, Dec., 40–49). Strain in bonds between steel specimens is measured by capacitance methods. The calculations are indicated using the Lorenz–Lorentz equation.

MACHINING AND MACHINABILITY

Review of the Metal Cutting Analyses of the Past Hundred Years. I. Finnie. (*Mech. Eng.*, 1956, **78,** Aug., 715–721). The author reviews critically the various analyses of metal cutting developed over the past hundred years. (71 references).—D. H.

Cutting Tools: Great Promise for New Materials. R. T. Hook. (*Iron Age*, 1957, **179,** Mar. 14, 134–136). A discussion of titanium carbide and Ti and Mo borides and other ceramics.

Why Leaded Forgings Favor Machinists. (*Iron Age*, 1957, **179,** Mar. 14, 138–139). A report on milling and machining tests on various grades of leaded steel, especially Alco Products Materials.

Metal-Cutting Evaluation. F. J. Daasch. (*Steel Processing*, 1957, **43,** Mar., 136–141). A review of machining including discussions of tool life measurement, tool forces and special tests using an analogue computer on 13 variables. (20 references).

Computers: Short-cuts to Better Machinability. H. J. Siekmann. (*Iron Age*, 1956, **178,** Nov. 22, 98–99). The machinability computer is finding use in many plant planning and methods departments to establish proper machining speeds and feeds for the h.p. available, and to provide answers about numerous machining problems, some of which are listed. Several examples of the use of computers are quoted.

Vibrations Caused by Chip Formation. P. Landberg. (*Microtecnic*, 1956, **10,** No. 5, 219–228). Investigations are described of the periodical variation of the cutting forces in chip formation, using a lathe fitted with measuring devices. The measured frequencies were compared with those determined by calculation. The natural frequencies of the lathe components and vibrations caused by the lathe transmission were also determined. The trials have not been completed, but some conclusions are drawn regarding the possibility of controlling chip vibrations.—L. D. H.

Decrease of Dimensional Discrepancies by Mannesmann Piercing Process. F. Köves and R. Hantos. (*Kohászati Lapok*, 1956, **11,** (10), 442–451). The decrease of dimensional discrepancies depends on the construction and state of the pilger rolls, piercer rods and charging devices and on the applied technology. The authors deal with these aspects in detail.—P. K.

Analysis of the Stresses in a Cutting Tool. F. R. Archibald. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** Aug., 1149–1154). The stresses in a cutting tool during metal cutting are analysed using elasticity theory. The tool is considered as a wedge having normal and tangential loading on one face. Equations for the stress components at any point of the tool tip are obtained. Particular attention is given to the edge of the tool where stresses of several hundred thousand lb/in^2 are found.—D. H.

On the Tool-life and Temperature Relationship in Metal Cutting. F. F. Ling and E. Saibel. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **7,** July, 1113–1117). The empirical relationship of Schallbroch, Schaumann, and Wallichs between tool life and cutting temperature is examined in the light of recent developments in rupture theory. Cutting-tool failure is viewed essentially as a rupture process and the data relating tool life and temperature are interpreted from a reaction-rate theory point of view.—D. H.

Contribution to a Solution of the Problem of Short Duration Tests for Determining the Life of Turning Tools. E. Bickel. (*Microtecnic*, 1956, **10,** (5), 209–214). In studying the various factors determining turning tool wear, it was found that the limiting value of the cratering of the top rake, (as measured by the angle between the tangent to the crater circle at its intersection with the top rake face and the direction of the latter) is constant. A graphical method was devised for determining the tool life without testing to destruction; the results obtained were reasonably accurate.—L. D. H.

The Mechanism of Crater Wear of Cemented Carbide Tools. K. J. Trigger and B. T. Chao. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** July, 1119–1126). Wear of cemented carbide tools on the top surface is examined in the light of the mechanism of frictional wear proposed originally by Holm and modified by Burwell, Strang, and Orchard. Wear at the top surface is essentially of the transfer type and the formation of crater wear is strongly temperature-dependent. For a given tool-work combination the top face wear can be correlated with tool-chip interface temperature in a manner predictable from the simple laws of adhesion wear in combination with the theory of rate process.—D. H.

The Accurate Measurement of Wear Scars on Cutting Tools. J. Taylor. (*Machinery*, 1957, **90,** Apr. 26, 927–934). Checks by dimensional measurement, weighing and radioactive isotopes are described and microscopical methods and the wear scar planimeter and its use are given in detail.

How we Grind Powdered Steel Gears to 4–6 Micro inches. A. Roberts. (*Prec. Met. Mold.*, 1956, **14,** Aug., 59–60, 62). The accurate grinding of gears produced by powder metallurgy is described and the economic advantages of the process given.—D. H.

On the Surface Roughness in Grinding. K. Sato. (*Tech. Rep. Tôhoku Univ.*, 1955, **20,** (1) 59–70). An analytical formula for roughness is advanced.

"Transparent" Wheel Takes Guessing Out of Grinding. (*Iron Age*, 1956, **178,** Dec. 6, 138). A grinding wheel supplied by Carl Hirschmann Co. Inc. has a number of small slots through its body so that, at top speed, it appears transparent. With a horizontally-rotating wheel and the workpiece held beneath, overgrinding is easily avoided.—G. F.

Handle Chips Efficiently For Greater Shop Profits. J. E. Hyler. (*Iron Age*, 1956, **178,** Nov. 22, 102–103; Nov. 29, 88–90). The author first gives details of the methods available for the extraction and reconditioning of cutting oil from the metal chips. Recovery varies from 20 to 100 gal per t of chips handled. He then briefly outlines the details of equipment used in the chip-handling system, including special conveyors, chip washers and driers, and briquetting machines, and mentions automatic controls in continuous handling systems.—G. F.

Application of Electro-Erosion to Metal Working. H. Opitz. (*Microtecnic*, 1956, **10,** (5), 203–208). The principles of electro-erosion by means of a spark discharge are first described briefly. The influence of the process on the surface structure are outlined; the factors influencing the design of an electro-erosion spark discharge machine are enumerated and some applications of the process are given.—L. D. H.

CLEANING AND PICKLING

Proper Cleaning Methods Pay Dividends. L. F. Spencer. (*Metal Finishing*, 1957, **55,** Apr., 56–61). Cleaning materials are listed and classified and processes are described in general terms. Equipment is also classified and principles set out.

Cleaning Metals and Alloys. C. B. F. Young. (*Metal Finishing*, 1956, **54,** Oct., 57–60, 65; Nov. 56–59, 65). A general review of surface contamination and its removal, polishing and buffing compounds and the use of ultrasonics is given. The general principles of the control of alkaline cleaners, wetting agents and non-ionic surface-active agents is discussed in the second article and methods for cleaning metals are given. Non-ferrous metals are treated as well as iron and steel.

Technical Developments of 1956. N. Hall. (*Metal Finishing*, 1957, **55,** Jan., 42–52A). A review of developments in cleaning, pickling, polishing electrodeposition and associated processes is given. (421 references).—A. D. H.

The Pretreatment of Metal Surfaces. M. Lewis. (*Melat Finishing J.*, 1957, **2,** Jan. 29–36). Cleaning methods are described briefly and proprietary phosphating processes are discussed in detail.—A. D. H.

Wetting Agents and Buffers in Cleaning and Electroplating. E. Engel. (*Products Finishing* 1957, **21,** Feb., 32–35). An elementary account of the influence of soaps and detergents on surface tension in electroplating and pickling. Buffering agents are mentioned.—A. D. H.

Mechanical De-Scaling of Wire. S. Hájek. (*Hutník*, 1956, **6,** (9), 271–275). [In Czech]. Modern methods and machines used for wire descaling and drawing are discussed. Descaling by pickling is judged to be in the process of becoming obsolescent except for certain alloy-steel wires.—P. F.

Mechanical Descaling, Especially by Bending, in the Processing of Wire. C. Eisenhuth. (*Stahl u. Eisen*, 1957, **77,** March 21, 323–334). The author presents the results of a questionnaire to all wire-processing firms in Western Germany. About 18% of all wire is now mechanically descaled but mostly where the surface quality is of secondary importance. The success of mechanical descaling varies from plant to plant and depends on a number of factors such as composition of the wire, drawing speed, reduction per pass, lubricant, composition of the scale, and type of machine employed. The economics of the process, with special reference to saving in water and sulphuric acid and the neutralization of the spent liquors, are also considered.—T. G.

The Almco Supersheen Barrel-finishing Process. (*Machinery*, 1957, **90,** Apr. 26, 923–926). Fixture machines are reviewed and typical fixtures are described and illustrated.

Control of Pickling Prior to Galvanizing Reduces Waste. J. L. Collins. (*Products Finishing* 1957, **21,** Feb., 43–46). Pickling of pipe at 75° F for 100 hr is shown to require less acid, reduce fumes and reduce hydrogen absorption when compared with shorter times of pickling at higher temperatures. These advantages are stated to outweigh the extra plant needed.—A. D. H.

PROTECTIVE COATINGS

Selecting Electroplates for Iron Powder Parts. W. H. Safranek and M. W. Wirth. (*Mat. Methods*, 1956, **44,** Nov. 104–109). Plating with Cd, Zn, Ni, Cr and Cn is described and appearance, plating thickness, and resistance to humidity and salt spray tests are reported.

Production of Smooth, Fine Grained Electrodeposits. G. Gabrielson. (*Metal Finishing*, 1956, **54,** Nov., 52–55). The theory of the production of fine grained smooth, adherent electrodeposits is discussed with reference to limiting current density and the cathode film. General practical recommendations are made.—A. D. H.

Germanium Rectifiers Power Plating Line. (*Steel*, 1957, **140,** Mar. 11, 168). A semi-automatic bumper plating line at Rheem Automotive Co. is powered by germanium rectifiers producing 160,000 amps. d.c. Brief details of the units are given.—G. F.

Barrel Plating Costs. E. A. Ollard. (*Metal Finishing J.*, 1957, **3,** Jan., 13–17, 36). The importance of costing in the small barrel plating shop is emphasized and a suitable method is proposed.—A. D. H.

A Comparative Survey of Stoving by Convection and Radiation. L. Walter. (*Metal Finishing J.*, 1955, **1,** Oct., 417–424, 451; 1956, **2,** Jan., 23–29, 34; 1956, **2,** Mar.-April, 91–100, 102; Aug., 285–294, 298; Nov., 411–417, 440). After dealing with fundamental aspects of heat transfer and thermal efficiency in stove drying, economic and production factors affecting the choice of convection stoves and radiation ovens are presented in detail. Examples of the design and operation of infra-red heated stoves, sheathed wire elements and forced convection ovens are given.—A. D. H.

Coatings for Protection of Electroplating Equipment. M. Perez. (*Metal Finishing*, 1957, **55,** Apr., 62–64). Wax coatings, solvent-type, lacquers, plastitols, and methods of application are briefly reviewed.

The Growth and Properties of Metal Whiskers. S. M. Arnold. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 26–31). Growth on electroplate is described and illustrated, conditions for inhibition and promotion of growth are mentioned and its mechanism, and X-ray diffraction and bend tests are referred to. (30 references).

Chromium Plating from the Trivalent Bath. M. R. Zell. (*Metal Finishing*, 1957, **55,** Jan., 57–58). Details of the development and operation of a bath containing $Cr_2(SO_4)_3$ 300–400, $(NH_4)_2SO_4$ 200–300, Urea 300–450 gm/litre and formamide 3–20 ml/litre and operated at 80°–100° F are given. The deposits are resistant to cold HCl and the bath is suitable for the production of chromium alloys.

Chromium Plating Over a Chromate Film. J. E. Hoover. (*Products Finishing*, 1957, **21,** Jan., 46–49). Preliminary results of salt spray tests indicate that chromium deposited on zinc coated steel which had been treated to obtain a chromate coating in "Cronak", indicate that the treatment improves corrosion resistance.—A. D. H.

Electroplating Chromium on Unusual Alloys. C. Levy. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 219–222). Plating of 9 high-temperature alloys including SAE4340, and 502 and 19–9 DL Stainless steels is described.

Testing the Porosity of Chromium Plating. A. A. Polyakov and D. N. Garkunov. (*Zavodskaya Laboratoriya*, 1956, **22,** (4) 482–484). [In Russian]. A special microscope for the examination and photography at magnifications of × 30 of chromium plating on cylinders is described. The plating porosity is evaluated by comparison with standards.—S. K.

Bright Nickel Plating. I. R. Bellobono. (*Metal Finishing J.*, 1957, **3,** Jan., 5–9, 12). Theories of the actions of brighteners added to nickel plating baths are presented with special reference to the influence of organic additions in increasing cathode potential.—A. D. H.

A Study of the Effect of Several Organic Addition Agents on the Hardness and Residual Stress in Nickel Deposits. I. L. Newell. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*,

1956, **43,** 101–104). Greater hardness was obtained from a sulphamate bath by addition of saccharin, *p*-toluenesulphonamide or naphthalene-1:3:6-trisulphonic acid.

Nickel–Iron Alloy Electrodeposits for Magnetic Shielding. I. W. Wolf and V. P. McConnell. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 215–218). Magnetic measurements are outlined as well as plating methods and compositions.

Composite Castings of Aluminium Bronze and Steel. Improved Corrosion Resistance and Stiffness. C. H. Meigh and G. E. E. Marshall. (*Engineering*, 1957, **183,** May 10, 594–595). The casting of aluminium bronze on steel cores, the properties and uses of the products, and advantages of the process are briefly described.

A Second Look at Radiographic Inspection of Lead Linings During Fabrication. W. Skiba. (*Mech. Eng.*, 1956, **78,** Dec., 1125–1127). Apparently small defects located in earlier studies led to failures. Improved techniques are outlined.

Overlay Plating of Steel-Back Aluminium-Lined Sleeve Bearings. A. H. Beebe, jun., B. F. Rothschild, and G. J. Le Brasse. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 164–171). Plating of Pb alloy is described. Preplating treatments to obtain good bonding, low diffusion, small size change and low cost are outlined. Cleaning, pickling and plating baths and observations are given and the construction of tanks, racks and other equipment is discussed.

"Steel Sandwich." (*INCO Mag.*, 1956, **26,** Oct., 26–29). A review of clad steel and its uses during 25 years.

Some Characteristics of Electroformed Iron Deposits. A. M. Max and G. R. Van Houten. (*Proc. Ann. Conf. Amer. Electroplaters' Soc.*, 1956, **43,** 136–150). Variables were investigated in plating from $FeCl_2$ solution with special regard to stress and pitting. Effects of Cu, Ni, and Mn were determined and the results are summarized.

A Tool for Decision. Acceptance Sampling by Variables and How it Works. R. H. Moore. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 128–135). An example is worked out for 1 in. square Cd-plated steel samples.

An Experimental Investigation of the Metal Spraying Process. A. Matting and K. Becker. (*Electroplating*, 1956, **9,** Mar., 85–88; April, 126–128; May, 147–148, 153). A continuation of *Ibid.* 1955, April. High speed photography was used to investigate the production of metal particles produced in an oxy-acetylene spray gun. To prevent oxidation it was found that a neutral flame, melting outside the flame centre, acceleration of the particles in a neutral atmosphere and high gas velocity were necessary . (57 references).

Steam Atmosphere Heat Treating Promotes Special Metal Characteristics. F. L. Spangler. (*Indust. Heating*, 1957, **24,** Mar., 478–480, 482, 484, 486, 488). Oxide finishes on steel parts and improved properties of sintered powders are produced. Furnaces are described and uses illustrated.

The Effect of Very Small Amounts of Foreign Atoms on the Structure of the Iron–Ferrous Oxide Interface. R. Sifferlen and C. Bourelier. (*Compt. Rend.*, 1957, **244,** Apr. 15, 2160–2163). Irregularities in the interface are shown to correlate with foreign atoms (Ni, C, O., etc.)

A Study of Phosphate Treatment of Metals. L. O. Gilbert. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1956, **43,** 195–208). Analysis of the solutions and compositions of H_3PO_4, $FeHPO_4$ and its point of incipient precipitation, Mn and Zn phosphate solutions and the coatings formed and accelerators such as NO_3^-, NO_2^- and ClO_4^- are all discussed. (12 references).

Vinyl Coatings for Metal Products. R. A. Calsibet. (*Mat. Methods*, 1957, **45,** Mar., 130–134).

Preparation of Metal for Vitreous Enamelling. A. H. Symonds. (*Inst. Vit. Enamel. Bull.*, 1956, **7,** Nov., 20–23). Removal of grease and dirt, rust and scale, roughening the surface to promote adhesion and nickel pre-coating are outlined. Alkali cleaning, acid pickling, nickel dip, etching, and equipment necessary are briefly treated.

Abrasion Resistance of Vitreous Enamel. (*Metal Finishing J.*, 1956, **2,** Nov., 410, 440). An instrument developed by the U.S. National Bureau of Standards is described. The enamelled specimens are rotated in contact with an abrasive slurry under controlled conditions. The test is reproducible and the results agree with service behaviour.—A. D. H.

The Effect of Some Mill Additions on the Abrasion Resistance of a Titania-opacified Enamel. R. H. Ashby and B. K. Niklewski. (*Metal Finishing J.*, 1957, **3,** Jan., 19–24; discussion 24–28, 38). The effect of variation in clay content, the addition of quartz and zinc oxide and of changes in electrolyte content on the abrasion resistance of a titania-opacified enamel was studied using the Taber Abraser instrument. The abrasion resistance can be increased by increase in time of firing, additions of zinc oxide or quartz and by adding potassium chloride instead of sodium nitrite and potassium carbonate to the mill formula.—A. D. H.

Rokide Process. Flame-Spraying of Refractory Coatings for Metals. (*Foundry Trade J.*, 1957, **102,** Apr. 4, 417–419). Heat, corrosion and erosion-resisting coatings are formed.

Hot Spray Painting—How and Why to Use it. (*Proc. Met., Mold.*, 1956, **14,** Sept., 86–90). The advantages of spray painting at 140° F are given, together with illustrations of its use.—D. H.

POWDER METALLURGY

Eight Jobs That Cost Less by Powder Metallurgy. (*Precision Met. Mold.*, 1956, **14,** Nov., 45–47). Examples of clock and timer parts made from iron and other powders are given.

Slip Casting of Stainless Steel Powder. I & II. W. G. Lidman and R. V. Rubino. (*Prec. Met. Mold.*, 1956, **14,** Aug., 40–41, 83; Sept. 64–66, 98). A method is described for the production of slip cast components in stainless steel powder. Relatively good physical properties are obtained, but the results are not reproducible. Slips containing powder, water, ammonium alginate and polyvinyl alcohol were cast into plaster of paris moulds by centrifugal casting and the resulting sample sintered at 1320° C/16 hrs. Brief details are given of the properties to be expected.—D. H.

Sintered Steel—For High Shear Strength Service. J. D. Howell. (*Prec. Met. Mold.*, 1956, **14,** Aug., 51, 56). The manufacture of a self-lubricated splined bushing in porous sintered steel is briefly described.—D. H.

Roles of Structures and Atmospheres in the Kinetics of Sintering of Carbonyl Iron. G. Cizeron. (*Compt. Rend.*, 1957, **244,** Apr. 8, 2047–2050). Fritting is slower for γ than for α iron at 910–1000° because of the existence of a single autodiffusion mechanism and the absence of intergranular diffusion. The effects of sintering in H_2 and *in vacuo* are observed, the former being much more rapid.

Metallic Muffle for High-Temperature Sintering. E. N. Mazza. (*Precision Met. Mold.*, 1956, **14,** Dec., 44–45). A continuous type muffle with Inconel heaters working at 1300–1350° is described and its operation and costs surveyed.

The Electrical Conductivity of Powders During Sintering. J. Martinet and S. Tacvorian. (*Rev. Mét.*, 1957, **54,** Jan., 65–70). Study of the electrical conductivity of metal powders or metal oxide powders during sintering shows that prior to the actual sintering process (which appears as a shrinkage) the electrical conductivity alters considerably and becomes very similar to that associated with a solid metal. This rapid change in conductivity is considered to be related to the beginning of sintering.—B. G. B.

FERRITES, CERMETS, AND CARBIDES

Certain Properties of Ferrites. J. K. Galt. (*Bell Lab. Record*, 1957, **35,** Apr., 126–130). A review, mainly of the theoretical aspects of magnetic properties, is given.

Anisotropy Constants and g Value of Nickel Ferrite. D. W. Healy, jun. and R. A. Johnson. (*Phys. Rev.*, 1956, **104,** Nov., 634–636).

The Structure of Calcium Ferrite. B. F. Decker and J. S. Kasper. (*Acta Crystallographica*, 1957, **10,** Apr. 10, 332–337).

On Observation of the Magnetic Viscosity of Ferrites at Low Temperatures, R. V. Telesnin and I. A. Lednev. (*Doklady Akad. Nauk S.S.S.R.*, 1957, **112,** (1), 48).

Cermets for High-Temperature Service. J. T. Norton. (*Mech. Eng.*, 1956, **78,** Apr., 319–322). A review of properties and structures.

Ceramics as Basic Engineering Materials. E. J. Smoke and J. H. Koenig. (*Mech. Eng.*, 1956, **78,** Apr., 315–318). A review of the properties of ceramics (including carbides and borides) compared with metals and a survey of their refractory and other uses are given.

PROPERTIES AND TESTS

Experimental Equipment for Mechanical Testing at Low Temperatures. F. Maratray. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14**, 169–199). A comprehensive illustrated account of experimental techniques for the testing of the mechanical properties of metal specimens at low temperatures is given. Methods of refrigeration and of temperature control are explained in detail.—B. G. B.

Problems in Steel Specifications. The Development of an AISI–SAE Standard Steel. W. R. Miller, (*Steel Processing*, 1957, **43**, Apr., 208–210). A brief account of classification and codification is given. **Application Guides in Specifying Steels.** J. Gurski. (210–213). Selection of steels for lowest cost and the calculated risks that may be taken and the use of preferred gauges is briefly described. **Specifications and Steelmaking Problems.** D. H. Ruhnke. (213–214, 231).

Testing Spring Strip. M. I. Zlotnikov. (*Zavodskaya Laboratoriya*, 1956, **22**, (6), 729–731). [In Russian]. An empirical formula is proposed which enables the limiting angles of springiness of spring strip to be found accurately in relation to specified allowances for thickness and strength. The use of this formula makes it possible to replace tensile-strength determinations by angle determinations, and efforts to improve the appropriate apparatus are urged.—S. K.

The Metallurgy of Ductility. A New Law. T. Ryan. (*Australasian Eng.*, 1957, **49**, Jan. 7, 48–52). An account of Bridgman's work on steel under very high pressures and the concept of the pressure coefficient of ductility and the dependence of plasticity on pressure. Wire-drawing trials under hydrostatic pressure are also discussed.

New Developments in Flaw Detection. (*Indust. Finishing*, 1956, **9**, Nov., 214, 217). A fluorescent ink composition used for crack detection is described.

Operational Research in the Iron and Steel Industry. H. G. Jones. (*Iron Coal Trades Rev.*, 1957, **174**, Jan. 11, 97–102). Applications of operational methods to non-technical problems in the Steel Co. of Wales are surveyed.

French Standard Specifications for the Iron and Steel Industry. M. E. Jaudon. (*Chim. Anal.*, 1956, **38**, June, 195–200). A review of their development and the amount of standardization necessary to obtain identical analyses from different laboratories, with illustrations of standard equipment.

The Testing of Materials and Welds used in the Construction of Hydro-Electric Power Stations. W. Stauffer and A. Keller. (*Rev. Soudure*, 1956, **12**, (4), 220–242). [In French]. The authors describe detailed studies and researches which were carried out to find the best methods of welding and testing large weldments used in the design of hydroelectric power stations. Statistical data are given on the behaviour of steel plates, their mechanical properties, and resilience. The destructive and non-destructive testing of welds is discussed.

Instrument Encyclopaedia. E. W. Battey and A. Linford. (*Automation Ind.*, 1956, **3**, June, 125–128; July, 160–163; Aug., 184–186; Sept., 200–203; Oct., 229–231; Nov., 254–257; Dec., 276–281). An alphabetical list of definitions, descriptions, and explanations of terms relating to the instrument industry.

Nature of the Damping of Vibrations. V. I. Prosvirin and N. N. Morgunova. (*Vestnik Mashinostroeniya*, 1952, **21**, (5), 53–59). Internal friction in plain carbon and austenitic steels is investigated and a damping mechanism suggested. Cast iron is also considered and properties are referred to the relative amounts of different constituents present: ferrite, pearlite, austenite, cementite, or graphite. The more ductile component, it is suggested, is the more important.

Resilience Testing of Metallic Materials. E. Forcellini. (*Rivista Mecc.*, 1955, **6**, Oct. 29, 21–24). [In Italian]. After a brief reference to the advantages of resilience or tenacity tests, the author describes the Charpy pendulum testing machine and gives typical test results for carbon and alloy steels.

Resilience of Stainless Steel at Low Temperatures. P. Foffano. (*Calore*, 1956, **27**, Feb., 55–57). [In Italian]. The author discusses the behaviour of stainless steels at very low temperatures in the region of − 200° C. Comparative tests on various steels are described. The results given make it possible to draw up a specification which will ensure safe working at various pressures and temperatures.—M. D. J. B.

The Damping of Mechanical Vibrations During the Formation of Martensite in Iron–Nickel Alloys. E. Scheil and J. Müller. (*Arch. Eisenhüttenwesen*, 1956, **27**, Dec., 801–805). In the $\gamma \rightarrow \alpha$ transformation of irreversible iron–nickel alloys, transformation is observed to start considerably earlier in the curve for the damping of mechanical vibrations than in the curves for the modulus of elasticity and electrical resistance. It is shown that this " preparatory effect " will not occur if the sample is heated to a temperature below that of the $\alpha \rightarrow \gamma$ transformation at a point just above the starting point of transformation on the resistance curve.—L. J. L.

Nature of Plastic Deformation of Surface Zones of Working Parts. K. V. Savitskiĭ and M. P. Zagrebennikova. (*Doklady Akad. Nauk S.S.S.R.*, 1955, **103**, (4), 605–608). Copper and aluminium were submitted to friction on mild steel plates or compressed under static loads or by impact and the microhardness observed. Effects of annealing are also noted. Strain hardening and recovery may occur simultaneously.

Plastic After-effect in Metals. D. M. Vasil'eva and L. S. Evlashin. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (6), 1351–1356). [In Russian]. Residual changes of dimensions of specimens observed during their heating after a preliminary plastic deformation by torsion or bending (plastic after-effect) are discussed. Plastic after-effects are caused by relaxation of residual macro- and micro-stresses formed by preliminary plastic deformation. Using specimens of 5 carbon steels containing various amounts of carbon it was found that low and medium alloy steels produce after heating a positive after-effect. Steels of eutectoidal composition give a negative after-effect. Both components of after-effect caused by relaxation of macro and micro-stresses were determined. Phenomena described in this work are of practical interest since they permit the prediction of the sign and size of the after-effect causing wobbling of parts during their heating after cold straightening.—V. G.

On the Nature of the After-Effect in Metals. D. M. Vasil'ev. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (6), 1357–1365). [In Russian]. In order to explain after-effects observed on heating plastically deformed specimens a rheological scheme consisting of two Maxwell elements connected in parallel is proposed. Such a scheme depending on the relation of the relaxation times of its components produces after the removal of microstresses (caused by preliminary deformation) either a positive (abnormal) or a negative (normal) after-effect.

A Possible Mechanism for the Fracture of Metals. F. E. Fujita. (*J. Phys. Soc. Japan*, 1956, **11**, Nov., 1201). A possible mechanism for the production of sufficiently large stress-concentrating voids by plastic flow in conjunction with dislocations is outlined.

On the Elastic Modulus E_0 of Graphitic Iron Materials. W. Grundig. (*Giesserei, Technisch-Wissenschaftliche Beihefte*, 1956, Sept., (16), 809–814). The elastic modulus E_0 is considered as a basic mechanical property of material, and the factors which influence it discussed. The E_0-moduli of graphitic steel, malleable and grey cast iron, sphaerolithic cast iron, and cast iron with an acicular structure are considered as functions of graphite content. The idea of ' steel similarity ' is introduced. The stresses in the matrix material are calculated and the influence of the form of the graphite is described.—R. J. W.

Damping Investigations of Iron–Chromium Alloys. K. Bungardt and H. Preisendanz. (*Arch. Eisenhüttenwesen*, 1956, **27**, Nov., 715–724). Damping measurements have been made in a vacuum apparatus on iron–chromium alloys up to 45% Cr. Three separate damping maxima were found at 220°, 600°, and 720° C. Nitrogen and carbon were found to have a decisive effect on their formation.—L. J. L.

Geometrical Description of Dislocations. W. G. Burgers. (*Metalen*, 1956, **11**, Oct. 31, 451–457). [In Dutch]. This paper is the introductory lecture to a symposium held in Jan. 1956 at Eindhoven. The author discusses dislocations, calling them a special type of lattice distortion characterized by a line of severely disturbed lattice and a vector. Several kinds of dislocation occur such as a screw dislocation where the line and vector are parallel, an edge dislocation when they are perpendicular, and a mixed type of dislocation. Numerous drawings appear in the text and there are various references taken from the international technical press.

On the Behaviour of Cast Iron under Tensile Stress. F. Hickel. (*Giesserei, Techn.-Wissensch. Beihefte*, 1956, Sept., (16), 815–828). An investigation is described in which the stress–strain characteristics of a large number of different cast-iron specimens were determined. The specimens had

had a variety of heat treatments producing a number of different textures. Time–elongation characteristics and recovery effects were also investigated. Strain measurements were made after numerous applications and removals of the load for various values of the load. The results are clearly tabulated.—R. J. W.

Tension Tests on Steels and Non-ferrous Metals at High and Low Temperatures in a Hard Testing Machine Using Elongation Strips to Measure the Force. A. Kochendörfer and W. Wink. (*Arch. Eisenhüttenwesen*, 1957, **28**, Jan., 41–48). A testing machine characterized by inertia-less power measurement is described. The determination of the elastic limit and of the true stress–elongation curve in the constricted area for steels and non-ferrous metals at − 180 to 800° C is discussed.—L. J. L.

An Apparatus for the Determination of Stress–Strain Properties at High Rates of Strain. R. J. MacDonald, R. L. Carlson, and W. T. Lankford. (*Proc. Soc. Exper. Stress Anal.*, 1956, **14**, (1), 163–170). High-speed tensile testing at rates of 0·25–190 in./min can be carried out. Recording devices are described. Data on deep-drawing sheet steel are presented.

Yield and Fracture Point Limit Surfaces. M. Petitdidier. (*Rev. Mét.*, 1955, **52**, Oct., 764–770). The shape of the limit surfaces is determined from the Schnadt diagrams for steels. The yield point assumes a cylindrical form. Criticisms of the Schnadt theory are reviewed. An approximate formula is proposed to simplify the fracture limit surface by reduction to a quadratic form.—B. G. B.

The Nominal Cleavage Strength of Steel and its Importance for Welded Structures. T. M. Norén. (*Trans. N.E. Coast Inst. Eng. Ship.*, 1956, preprint, 87–112). Tensile test pieces with a brittle alloy welded to the edges are tested and the maximum load sustained in the presence of cracks is defined as "nominal cleavage strength." Impact and other brittle-fracture tests are correlated and a transition temperature is observed above which plastic deformation occurs over a large volume and below only locally in presence of cracks.

Nitrogen as an Alloying Element in Steel. XII. Effect of Nitrogen on Quench-ageing of Steels. Y. Imai and T. Ishizaki. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, July, 318–322). [In Japanese]. Tests were made on steels containing 0·02–0·03% and 0·15–0·20% of carbon. Specimens were quenched from 950° C, tempered at 700° C for 3 hours, quenched from temperatures in the range 300–700° C after heating for 3 hours at these temperatures, and aged at 30°, 50°, and 100° C. There is a clear correlation between the nitrogen content and quench-ageing. The ageing is reduced by adding aluminium or titanium or melting *in vacuo*. When the nitrogen content is below 0·005%, ageing due to carbon becomes apparent.

Practical Aspects of the Brittle Fracture of Steel. G. E. Tummers. (*Metalen*, 1956, **11**, Nov. 30, 496–502, Dec. 15, 528–534). [In Dutch]. The author first examines the various aspects of the causes of several catastrophic failures of iron and steel in civil engineering and shipbuilding constructions and goes on to give the results of a thorough investigation into the causes of a brittle fracture in a 150 mm dia. gas main. The latter had exploded into numerous pieces which were afterwards stitch welded together and then tested in the laboratory.—F. R. H.

Brittle Fracture Initiation Tests. C. Mylonas, D. C. Drucker, and L. Isberg. (*Welding J.*, 1957, **36**, Jan., 9s–17s). A study of the conditions which prevent the initiation of brittle fracture at nominal stresses below yield point. Welded and unwelded notched steel plates with various prestrains were pulled at various temperatures. Transversely prestrained plates with punched notches fractured consistently below yield under static loading.—U. E.

The Development of Experimental Apparatus for the Determination of the Tendency to Brittle Fracture at High Stress Velocities. E. Siebel and G. Menges. (*Arch. Eisenhüttenwesen*, 1957, **28**, Jan., 31–39). An apparatus to enable uni-axial tensile stress to be applied at high velocity to smooth test rods is described. The test rod is exposed to a rapidly revolving disc having an impact stud. Impact-velocities can be adjusted from 5 to 100 m/s.—L. J. L.

Brittle Fracture Propagation in Wide Steel Plates. W. J. Hall, R. J. Mosborg, and V. J. McDonald. (*Welding J.*, 1957, **36**, Jan., 1s–8s). A fundamental study of the propagation of brittle fractures in large steel plates is described. The plates are tested under various conditions of stress and temperature with a brittle fracture initiated at an edge notch by a wedge subjected to impact. General observations relating to strain response, crack speed, and fracture appearance are presented.—U. E.

475° C Embrittlement of Chromized Coatings on Low Carbon Steel. W. L. Chu. (*J. Met.*, 1955, **7**, Oct., 1121–1123). Cooling slowly through the 475° C range is found to embrittle chromium coatings. Structure and composition correlates with the chromizing process and the original carbon content.

An Investigation of the 475° Embrittlement of Iron–Chromium Alloys. K. Bungardt and W. Spyra. (*Arch. Eisenhüttenwesen*, 1956, **27**, Dec., 777–786). The changes have been determined, in light iron–chromium alloys of 18–45% Cr, of hardness, electrical resistance, elongation, thermal stress, and magnetization. It is concluded from the results that decomposition of the mixed crystal occurs at about 475°.

Factors Affecting Brittleness in Constructional Steels. P. E. Lagasse. (*Rev. Soudure*, 1956, **12**, (3), 178–196). [In French]. The author describes the various experiments carried out in the last few years which explain the modifications in grain structure which provoke transition phenomena in steels. Experimental evidence agrees well with modern theories on the formation and growth of hair cracks. The author reviews the various factors which are empirically known to be related to brittleness in constructional steels, and shows how the experimental evidence of tests can be used to assess the suitability of steels for structural work and their weldability. (23 references).—M. D. J. B.

Reflections on the Change of State Leading to the 475° Embrittlement of Iron–Chromium Alloys. W. Köster and A. von Kienlin. (*Arch. Eisenhüttenwesen*, 1956, **27**, Dec., 793–799). It is concluded that the change of state leading to the 475° embrittlement of iron–chromium alloys is due to a separation into ranges rich in iron and chromium respectively. It is assumed that the structure of the quenched iron–chromium mixed crystals deviates from the ideal mixed crystal structure. This latent state develops at higher temperatures and affects the properties of the alloys.—L. J. L.

Investigation of Strain-hardened, Low-carbon, Manganiferous Structural Steels after Annealing. III. A Physical Interpretation of Lattice Phenomena of Embrittlement Following the Annealing of Cold-formed Steels. F. Erdmann-Jesnitzer. (*Neue Hütte*, 1956, **1**, Nov., 555–560). Normal strain age-hardening of structural steels, the occurrence of reversible anomalies in the load-elongation diagram at room temperature—250°–400°–250°, strain age-hardening and caustic embrittlement, the effect of aluminium on age-hardening and a working hypothesis based on electron theory to explain it, are discussed.—L. J. L.

Influence of Cold Drawing SAE 1018 Steel upon Brittle Transition Temperature. H. Majors, jun. (*Journal of Technology, (Calcutta)*, 1956, **1**, June, 57–80). Tension-impact tests examined oscillographically showed a narrow temperature range in which fractures changed from ductile to brittle type. Cold-working by drawing raised the temperature range.

On Notch Brittleness Tests Employing a Notched Weld. A Discussion. H. M. Schnadt. (*Welding J.*, 1957, **36**, Jan., 8s, 17s, 22s, 26s). The author discusses the questions regarding notch brittleness which were raised in several papers published by Pellini, Eschbacher, Puzak, and Schuster. The new Schnadt test specimen, its preparation and application is described.—U. E.

On the Wear of Cast-iron Cylinder Liners. P. A. Heller and W. Glaser. (*Giesserei*, 1956, **43**, Aug. 30, 505–507). The literature on this subject is reviewed (8 references). Several experiments are described in which the wearing behaviour of 8 different alloy steels has been investigated. The composition, trade names, textures, hardness, and wear properties of these alloys are tabulated.—R. J. W.

An Examination of a Mild Wear Process. J. F. Archard and W. Hirst. (*Proc. Roy. Soc.*, 1957, **238**, Jan. 29, 515–528). The wear of a hardened high-speed tool steel rubbing on itself at 66 cm/s under loads of a few kg was examined by autoradiography, optical and reflexion and replica electron microscopy and other methods. The surfaces eventually become very smooth and loose debris plays the predominant part in wear at this stage.

Friction and Wear in Machines. Collection X. (*Academy of Sciences of the U.S.S.R., Moscow*, 1955, pp. 335). [In Russian]. **Foreword.** M. M. Khrushchov (3). **Influence of Rate of Sliding on Wear of Like Metals.** I. V. Kragel'skiĭ and E. M. Shvetsova

(5–34). **Methods of Testing Metals for Wear by Friction in the Presence of a Liquid.** M. M. Khrushchov and M. A. Babichev (35–69). A type Kh2–M machine for friction-wear testing with liquid present is described and the theory of testing by making a rotating disc wear a groove on a flat surface of the specimen is considered. Effects of various factors on test results have been studied. **Investigation of the Resistance to Wear of Carbon Steels after Gaseous Chroming in the Presence of Some Liquids.** M. M. Khrushchov, M. A. Babichev, and G. N. Dubinin (70–81). A type Kh2–M machine was used to test, in the presence of water or 0·5% potassium dichromate solution, two series of steels: (*a*) carbon steels with different carbon-contents after annealing and (*b*) the same steels after saturation with chromium from the gas phase. **Resistance to Abrasive Wear of Cast Irons of Different Composition and Structure.** M. M. Khrushchov and M. A. Babichev (82–90). Relative resistances to abrasive wear for some typical cast irons used in machine construction have been determined and compared with those of various steels and pure metals under analogous conditions. Least resistance was shown by iron with a ferrite structure obtained during casting or after annealing. **Service and Theoretical Investigations of Wear in Regulating Metal-cutting Machine Tools.** A. S. Pronikov (91–134). **Bearings with Facing Materials.** L. V. Krasnichenko (135–154). **Temperature at a Sliding Contact.** V. S. Shchedrov (155–296). **Investigation of Heat Evolution by Friction in a Sliding Bearing.** A. K. D'yachkov. (297–335).

Friction and Wear in Machines. Collection XI. (*Academy of Sciences of the U.S.S.R., Moscow*, 1956, pp. 351). [In Russian]. **Foreword.** M. M. Khrushchov (3–4). **Investigation of the Wear of Metals and Alloys by Friction against an Abrasive Surface.** M. M. Khrushchov and M. A. Babichev (5–18). The authors' previous conclusions on the relations between relative resistance to wear and hardness for technically pure metals and heat treated steels have been experimentally confirmed, an exception being silicon. Effects of mechanical working, heat treatment, and other factors have been studied. **Investigation of the Effect of the Hardness of an Abrasive and the Wear of Metals.** M. M. Khrushchov and M. A. Babichev (19–26). **Effect of Some Design Factors on the Wear of Open Bearings Accessible to Abrasive.** I. I. Trepenenkov and A. M. Cheryapin (27–46). **Investigation of the Wear of Linings and Piston Rings on Sludge Pumps.** V. S. Lomakin (47–80). **Investigation of Corrosion–Abrasive Wear of Steel with Application to Tubes of Water Economiser Boilers.** O. N. Muravkin and A. V. Ryabchenkov (81–107). The results of investigations by the Central Research Institute for Technology and Machine Design are described dealing with the dynamics of abrasive wear and gaseous corrosion and with the resistance to wear of various types of surface hardening and protection of boiler tubes. **Investigation of the Influence of the Nature of the Porosity of Chromium Plating on the Wear of Cast Iron.** D. N. Garkunov and A. A. Polyakov (108–120). This work deals with the quantitative evaluation of the influence of the nature of the porosity of chromium plating on the wear of type PLCh–1 cast iron, and presents a physical picture of the wear of a porous chromium surface layer. Laboratory friction machines were used in the research. **Classification and Calculation with respect to Wear of Connections of Machine Parts.** A. S. Pronikov (121–181). **Occurrence of a "White Phase" on a Friction Surface.** A. D. Kuritsyna (182–203). It is concluded that the "white phase" on friction surfaces is not due to nitriding and oxidation but to locally occurring phase changes in steel which need high temperatures and rates of cooling. It can arise in steels with various carbon contents and initial structures if conditions enable surface enrichment with carbon to occur. **X-Ray Structural Investigation of "White Crust" formed on a Friction Surface.** V. G. Lyutsau (204–209). It has been shown that the "white crust" of steel friction surfaces consists of cementite, and, possibly, of small amounts of carbides of the type Fe_xC. Some light has been thrown on the mechanism of the formation of this "crust." **Phase Transformations in Steel during Friction and Wear.** G. M. Zamoruev (210–237). Conditions for the occurrence of phase changes during the wear of steel are examined, the changes are classified and examples of individual types of phase changes are given, based on the author's experimental data. **Mechanism of the Wear of Railway Wheels.** T. V. Larin and V. P. Devyatkin (238–263). This deals with the structural changes in the surface layer of tyres after service, the effect of carbon content in non-alloy steel on surface layer structural changes during tests with friction, and the influence of low steel temperatures on such changes during friction. **Stability of the Equilibrium Position of a Journal on a Lubricant Layer.** M. V. Korovchinskiĭ (264–323). **Bibliography on Friction, Wear and Lubrication for 1953** (324–351).—S. K.

The Relation between Wear and Distance Run, for Steel and Coated Steel Surfaces. M. R. Piggott. (*Proc. Phys. Soc.*, 1956, **69**, Aug. 1, 857–858). Mild steel on mild steel in bearings, or with coatings of FeS and Fe_2O_3 gave a logarithmic relationship but Fe_2O_3 coatings did not. Liquid paraffin was used as lubricant, also with addition of diethyl trisulphide. The latter followed the equation with a constant intermediate between Fe and FeS.

Research on Materials and Surface Coatings for Aircraft Arresting Wire Rope and Hook Points. R. J. Macdonald, J. K. Thompson, and G. K. Manning. (*PB* 117567, 1954, pp. 18; TIDU List 624). High-pressure abrasion tests against "super-improved" plough steel, stainless steel, and Elginoy are described. Mo, Ta, and Elginoy coatings were studied.

The Temperature-dependence of the Susceptibility of Iron–Chromium Alloys. W. Köster and A. von Kienlin. (*Arch. Eisenhüttenwesen*, 1956, **27**, Dec., 787–792). The dependence of susceptibility on field strength at different temperatures in iron–chromium alloys of 17·9, 24·7, and 26·4% Cr contents has been measured.—L. J. L.

Studies on Low-alloy Steel Castings. II. Studies on Mechanical and Wear Resistant Properties of Low Mn–Mo Steel Castings. S. Miyazaki. (*Tetsu to Hagane*, 1956, **42**, Mar., 252–254). [In Japanese]. Relationships between mechanical properties and heat-treatment conditions are shown.—K. E. J.

On the Wearing Phenomena of Nodular Graphite Cast Iron. I. K. Ogawa. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Aug., 407–412). [In Japanese]. With nodular iron, the wear resistance increases as the amount of ferrite around the graphite decreases, and there is least wear when the matrix is wholly pearlitic. With a wholly pearlitic matrix, the wear resistance is better than with normal cast iron, but with a "bull's-eye" structure it is worse. Observations of the worn surface indicate that the thermal resistance of nodular iron is high. Alloying the iron with phosphorus improves the wear resistance.—K. E. J.

Change of Magnetic Susceptibility of Transition Metals and Alloys at their Melting Points. Y. Nakagawa. (*J. Phys. Soc. Japan*, 1956, **11**, Aug., 855–863).

An Analysis of the Magnetization Processes in Iron Single Crystals by an Electrical Method. R. Parker. (*Phil. Mag.*, 1956, **1**, 12th Series, Dec., 1133–1146).

The Magnetic Working Point of Permanent Magnets as an Indication of Quality and an Acceptance Standard. H. Neumann. (*Arch. Eisenhüttenwesen*, 1956, **27**, Aug., 539–543). Previous standard specifications for magnets are critically reviewed, including DIN 17 410. A method of expressing specifications by groups of numbers is described. The working point as an acceptance standard is discussed, and a testing instrument, based on the working point, is described.—L. J. L.

Magnetic After-Effect. II. T. Huzimura. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, Aug., 313–318). Explanation of the phenomenon on the exhaustion theory led to the same result as the formal theory. The origin of relaxation is discussed, it being suggested that the activation process of lattice imperfections might be the main origin of the effect.

Magnetic Properties of Magnet Alloys of Iron, Wolfram and Molybdenum. H. Masumoto and Y. Shirakawa. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, Aug., 319–324).

Gamma Loop Studies in the Iron–Silicon and Iron–Silicon–Titanium Systems. G. G. Bentle and W. P. Fishel. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1345–1348). Dilatation studies have been made on 15 binary and 38 ternary alloys to determine the Ac_3 temperatures and to establish the limit of the γ loop in the Fe–Si and Fe–Si–Ti systems.—G. F.

High Damping Ferromagnetic Alloys. A. W. Cochardt. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1295–1298). The author has measured the decay of the free torsion vibration, at torsion stresses between 500 and 8000 lb/in², of twisted wires of 55 binary and ternary alloys of cobalt, nickel, iron, and chromium. Especially high damping observed in some alloys is explained in terms of magneto-mechanical hysteresis. High-damping binary Co–Ni

alloys appear to be suitable base alloys for new steam turbine blade materials.—G. F.

Effect of Plastic and Elastic Stresses on the Losses and the Domain Configurations of Grain-Oriented 3 Pct Si–Fe. P. W. Neurath. (*Trans. Amer. Inst. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1319–1324). The author has observed that permanent, plastic elongation of about 0·1% almost doubles the 60-cycle watt losses of grain-oriented 3% Si–Fe alloys, whilst subsequent application of tension in the elastic range eliminates this loss increase. Domain structures corresponding to these effects have been studied, and their interpretation bears out the loss results qualitatively.—G. F.

Electrons in Metals. Institut International de Physique Solvay. (*Dixième Conseil de Physique, Bruxelles, Sept.* 1954, *Reports and Discussions*, 1956, pp. 366). **The Collective Description of Electron Interaction in Metals.** D. Pines. (9–70). Screening theory is developed as an approximation. **An Extension of the Hartree-Fock Method to Include Correlation Effects.** P.-O. Löwdin. (71–113). **Resistance of Metals at Low Temperatures.** D. K. C. Macdonald. (89–113). Shortcomings of the Grüneisen-Bloch law are discussed in terms of thermal vibrations of the lattice, static imperfections, and electron transport under a thermal gradient. **Some Experiments on the Thermal Conductivity of Metals.** K. Mendelssohn. (115–122). Anomalies in the superconductivity range are noted. **Experimental Methods for Determining the Fermi Surface.** A. B. Pippard. (123–157). The theory and experimental investigation of the anomalous skin and de Haas–van Alphen effects are reviewed. **Resonance Experiments and Wave Functions of Electrons in Metals.** B. Kittel. (159–182). Cyclotron, nuclear spin, and electron spin resonances are discussed separately. **Primary Solid Solutions in Metals.** J. Friedel. (183–220). [In French]. Free energy calculations and effects of atomic size are discussed. **The Creation and Motion of Vacancies in Metals.** F. Fumi. (221–225). Preliminary results are described on calculations of vacancy production. **Neutron Diffraction Studies of Transition Elements and Their Alloys.** G. G. Shull. (227–250). High temperature measurements are described and work on iron and Fe–Cr, Fe–Ni, Co–Cr, and Ni–Mn systems is outlined. **Antiferromagnetism and Metamagnetism.** L. Néel. (251–286). [In French]. α–Fe_2O_3 and rare earth ferrites are used as examples. **Superconductivity.** H. Frölich. (287–313). **The Empirical Relation between Superconductivity and the Number of Valence Electrons per Atom.** B. T. Matthias. (315–319). **Hall Effect in Ferromagnetics.** J. Smit. (321–328). **On the Electronic Theory of Transition Metals.** A. Seeger. (329–365). [In German]. A model relating valency electron fields to crystal form is advanced.

The Measurement of Crack Depth by the Direct-current Conduction Method. J. G. Buchanan and R. C. A. Thurston. (*Nondestructive Test.*, 1956, **14**, Sept.-Oct., 36–39, 43, 44). A method is described whereby the depth D of a crack at right angles to the surface in material of any thickness T can be measured, provided the crack is long in comparison with its depth, and the material is homogeneous and isotropic in its electrical conduction properties. Calculations are given for the case where $D = T = \infty$, and the experimental calibration for other values of D and T is discussed and illustrated with a laboratory apparatus. The prototype " Crack Depth Indicator " is described and its usefulness for crack propagation studies is exemplified by some typical applications.

Electronic and Ionic Properties of the Transition Metals. A. Roos. (*Chim. et Ind.*, 1956, **76**, Nov., 1032–1046). The Bloch and Brillouin theory of ferromagnetic phenomena and the Weiss theory of fields for magnetostriction effects are used. Bonding energy and other magnetic problems are reviewed and studies on anodic oxidation are used to derive an ionic diffusion coefficient which is applied to stainless steels and wear resistance. The ionic aspect of structure complements the electronic aspects.

Ultrasonic Shear Wave Testing. W. J. McGonnagle. (*Metal Progress*, 1956, **70**, Oct., 97–99). The employment of ultrasonic flaw detection in difficult sections by using shear waves instead of the more normal longitudinal waves is discussed.—B. G. B.

Where Betatron Inspection Fits in Metalworking. (*Iron Age*, 1957, **179**, Apr. 18, 111–113). Use for radiographic inspection of castings 3 in. thick and over and as a design tool for working out better techniques is outlined. Construction, lay-out and the handling of pieces for inspection are described.

Neutron Diffraction. K. Lintner. (*Berg- u. Hüttenmann. Monatsh.*, 1956, **101**, Nov., 238–246). The author compares X-ray, electron, and neutron diffraction and outlines their useful application. He gives a number of experimental results including, *inter alia*, FeCo, Mo, Ni–Mn, and Cr at various temp. down to 20° K. As the neutron has a magnetic moment, the orientation of the magnetic moments of the atoms in the test piece can be detected.—T. G.

Electrical Vibration Viscometer. G. I. Leskov and G. D. Shevchenko. (*Zavodskaya Laboratoriya*, 1956, **22**, (4), 492–496). [In Russian]. A new type of viscometer is described with which practically instantaneous determinations can be made of slag viscosities at high temperatures. A plate of suitable material (tungsten, graphite or ceramic) is immersed vertically in the slag and caused to perform forced oscillation in the vertical plane. The viscosity is found from the amplitude of the oscillation. The plate is attached to a spring-suspended iron core in a permanent magnetic field and provided with two windings which are supplied with stabilized A.C. through two identical opposed windings on a differential transformer. The position of the core effects the impedance of its windings, and the amplitude of the oscillations is converted into readings of a galvanometer.

Machine for Hot Strength Testing According to Programmed Variable Conditions. A. T. Gorbodei, I. P. Bulygin and N. I. Mikheev. (*Zavodskaya Laboratoriya*, 1956, **22**, (4), 486–490). [In Russian]. A new universal testing machine is described for the investigation of the high-temperature strength of materials in relation to the nature of changes of temperature and loading conditions. Its special feature is the possibility of making long-term strength tests not only with cyclic variations of temperature and simple load conditions, but also with complicated, multiple-step temperature and stress changes following a prearranged programme. The low thermal inertia of the furnace enables cooling rates of 200° C/min to be obtained. The machine has undergone prolonged service testing, the results obtained confirming the need for this type of test.—S. K.

Diffusion of Sulphur in Liquid Iron. I. Diffusion in Pure Iron. Y. Kawai. (*Sci. Rep. Tôhoku Univ.*, 1957, **9A**, Feb., 78–83). The coeff. has been measured from 1560–1670° C and an expression is given for its relation to temperature. Theoretical results from the reaction rate theory and Stokes–Einstein equation are compared with the findings.

Contribution on Methods of Investigating the Self-Diffusion of Tungsten. V. P. Vasil'ev and S. G. Chernomorchenko. (*Zavodskaya Laboratoriya*, 1956, **22**, (6), 688–691). [In Russian]. In the technique described the auto-diffusion of tungsten was studied with the aid of its radioactive isotope ^{185}W, the measurement of activity being carried out continuously. The activation energy of the process has been found.—S. K.

Orientation and Development of Special Constructional Steels. E. Herzog. (*Rev. Mét.*, 1957, **54**, Jan., 23–56). The properties of a number of high strength steels, low or medium alloyed, with restricted carbon contents (0·15%) are described in detail. These steels enable a saving of weight by higher yield points and ultimate strength. Low sensitivity to notch effect, low transition temperatures and low strain-ageing properties are possible. It is also possible to have a high ratio of transverse to longitudinal properties. By alloying with 3–6% chromium the resistance to corrosion in atmospheric and aqueous environments is enhanced.—B. G. B.

High-boron Alloy Steels. T. H. Middleham, J. R. Rait, and E. W. Colbeck. (*J. Iron Steel Inst.*, 1957, Sept., **187**, 1–14). [This issue].

New—A High Strength Stainless Alloy. (*Precision Met. Mold.*, 1957, **15**, Mar., 63, 87–88). CD–4MCu alloy containing 25–27% Cr, 4·75–6% Ni, 1·75–2·25% Mo and 2·75–3·25% Cu is described. It has corrosion resistance equal to that of 18–8 with superior mechanical properties.

Use of the Method of Correlation for Studying the Relation between the Mechanical Properties of Alloy Marks of Steel. P. V. Sklyuev. (*Zavodskaya Laboratoriya*, 1956, **22**, (3), 325–329). [In Russian]. An account is given of a statistical study of the relationships between different mechanical properties of alloy steels. The experimental material was obtained with commercial and experimental steels alloyed with chromium, nickel, molybdenum, tungsten, and vanadium and containing 0·28–0·45% carbon.—S. K.

Pig Iron and Blast Furnace Ferro-alloys, Chemical Compositions. (*Amer. Iron Steel Inst. Contrib. Met. Steel*, 1954, (44), June, pp. 20). A revision of Steel Products Manuals, June 1947–May, 1951. Standard Grades, Chemical Analysis, Ferroalloys and Sampling and Analysis of Ferroalloys are given. (Methods of analysis are referred to A.S.T.M. publications).

16–15–6 Alloy Fills a Need. M. Fleischmann. (*Steel*, 1957, **140,** Mar. 25, 102–105). The first superalloy steel with 16% Cr, 15% Ni, 6% Mo, 7·5% Mn, 0·07% C and 0·5 Si is described. Its mechanical properties and the effect of heat treatments are given and its uses indicated.

Conferences on the Activities of Industrial Research Laboratories. The Activity of the d'Imphy Research Service. M. X. Waché. (*Indust. Nat.*, 1956, (4), 57–80). A report on creep in high-temperature austenitic alloys, showing test-pieces and results with ferro-nickel and non-ferrous austenites, and other topics, is presented.

Tasks of Steel Advice Bureau, W. Küntscher. (*Technik*, 1957, **12,** Feb., 89–90). A Steel advice bureau has been set up at the Freiberg Institute for Special Steels. Some examples of possible uses for it are given.—J. G. W.

METALLOGRAPHY

Ultra-Violet Metallographic Microscope. T. G. Porokhova. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 336–340). [In Russian]. An experimental model of an ultra-violet microscope is described. With it metallographic sections can be photographed in different wave-lengths of the visible and ultra-violet parts of the spectrum or they can be examined visually on a fluorescent screen in wavelengths over 313 mμ. With visual examination a multi-coloured image is produced since on the green fluorescent image is superimposed an image in red rays which can pass through the whole optical system. The construction and use of the instrument are described and some results obtained illustrated. Some defects and possible improvements are briefly dealt with.—S. K.

Use of the Microscope for the Study of High Temperature Processes. I. N. Anikin. (*Zavodskaya Laboratoriya*, 1956, **22,** (7), 805–806). [In Russian]. A special installation with a binocular microscope having a working distance up to 70 mm and whose magnification can be changed rapidly from × 3 to × 120 has been used to study crystal formation at temperatures up to 1000° C. The temperature limit can be increased to 1300° C.—S. K.

New Viewpoints on Grinding and Polishing, Particularly of Metallographic Specimens. Z. Ministr. (*Hutník*, 1956, **6,** (9), 257–262). [In Czech]. Recent developments in polishing and grinding techniques are surveyed, and the suitability of diamond abrasives for rapid and efficient grinding of samples is discussed.—P. F.

Method of Etching Polished Sections for Showing Simultaneously Austenite and Pearlite Structure. V. S. Popov. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 317). [In Russian]. A two-stage etching process, first in alcoholic nitric acid and then electrolytically in aqueous chromic acid, has been used to reveal the microstructure of welded joints of austenitic with pearlitic steels.—S. K.

Equipment for a Sample-Etching Department. T. T. Drobyazko. (*Zavodskaya Laboratoriya*, 1956, **22,** (6), 747–748). [In Russian]. Equipment used at the Kuznetsk Metallurgical Combine for etching steel samples to reveal their macrostructure is described. A special scrubber is used to prevent corrosion by the exit gas.—S. K.

A Non-Destructive Method of Macrographic and Micrographic Surface Examination. P. A. Jacquet and A. Van Effenterre. (*Rev. Mét.*, 1957, **54,** Feb., 107–125). Two techniques of local electrolytic polishing and of transparent replica production are described, which allow macro- and micro- surface examination of any shape and size of object without mechanical sampling. A number of examples of the use of the technique are given.—B. G. B.

X-Ray Diffraction Studies on Precipitates and Inclusions in Steels Using an Extraction Replica Technique. G. R. Booker, J. Norbury, and A. L. Sutton. (*Brit. J. Appl. Phys.*, 1957, **8,** Apr., 155–157). The replica removes the material from the metal surface and is formed into a cylindrical specimen for powder camera use. Only a few min are needed and iron carbide, nitrides and metal sulphides have been extracted successfully.

Study of Carbides in Iron and Steel by Electrolytic Isolation Method (Report 1). Isolation of Cementite from Carbon Steel. T. Sato and T. Nishizawa. (*Tech. Rept. Tôhoku Univ.*, 1955, **20,** (1), 121–130). A cell for cementite isolation is described and electron micrographs were examined.

Separation of Cementite from Titanium Carbide. N. M. Popova and M. F. Rybina. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 274–275). [In Russian]. A procedure based on the different behaviour of cementite and titanium carbide towards hydrogen peroxide in the presence of fluoride has been developed whereby almost complete separation of these carbides can be achieved.—S. K.

Equilibrium of Carbon and Oxygen in Molten Iron Saturated with Carbon. S. Matoba and S. Banya. (*Tech. Rept. Tôhoku Univ.*, 1955, **20,** (1), 131–141). An empirical formula for graphite solubility is given. The oxygen content of molten iron saturated with carbon is higher than the value extrapolated from dilute solution. Equilibrium reactions are proposed.

Graphitization of Steel in Petroleum Refining Equipment and The Effect of Graphitization of Steel on Stress-Rupture Properties. J. G. Wilson. (*Weld. Res. Council Bull. Series*, No. 32, Jan. 1957, pp. 44). Tests on 554 specimens of C and C–Mo steels removed from refining plants are reported. Graphite was found in 33·8%. High Al, high temp. and the process used all affect graphitization. ASTM A106 showed the greatest tendency and ASTM A285 plate the highest resistance. Accelerated tests at 1025° F/1000 hr were carried out, the results cannot altogether be explained as yet. Stress-rupture tests now being carried out may provide more exact data on the effects of graphitization.

Application of Autoradiography to the Study of Intra-Crystalline Liquation in Steel. I. E. Bolotov, M. I. Gol'dshtein, A. A. Popov and A. B. Fedorov. (*Zavodskaya Laboratoriya*, 1956, **22,** (6), 682–688). [In Russian]. After a brief introduction to the autoradiographic method as a tool for studying segregation of elements in steel, experimental details are given and some results obtained with S, P, and W are presented and discussed. ^{32}P, ^{35}S, and ^{185}W respectively, were used as tracers, in concentrations to give 1 mCu per kg metal intensity. With phosphorus and sulphur a structural Cr–Ni–Mo steel was used. The experiments with tungsten gave more detailed information on the effect of cooling rate on intra-crystalline liquation, which was evaluated by microphotometric measurements on the autoradiographs.—S. K.

Device for Determining the Quantity of Alpha-Phase in Stainless Steel. V. G. Mikheev and G. L. Kudryavtsev. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 341–342). [In Russian]. An instrument developed at the Kuznetsk Metallurgical Combine is described in which the content of alpha-phase in stainless steel is found from the induced e.m.f. in a coil in whose magnetic field the specimen is inserted.

Sensitivity of an Anisometer and Experimental Error in Studying Phase Transformations. K. A. Malinina. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 312–314). [In Russian]. Results obtained with an Akulov anisometer in studying the isothermal transformation of austenite in high-speed steels are compared with those of other methods and conclusions on the instrument and its experimental errors are drawn.

Use of the Magnetic Method for Studying Phase Transformations in Alloys Having Two Ferromagnetic Phases. Yu. D. Tyapkin. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 309–311). [In Russian]. The author has developed a method for excluding from the total magnetic saturation of a specimen with two ferromagnetic phases that portion of the saturation due to the second phase. The method has been applied to Fe–Ni (27% Ni) and Fe–Ni–Ti (27% Ni, 1·5% Ti) alloys.—S. K.

Pearlite-Austenite Change: Conversion by Heating Effect of Electric Current. P. G. Morgan. (*Iron Steel*, 1957, **30,** Mar., 108). The author summarizes recent Russian experimental work on the α–γ conversion, using the heating effect of an electric current to give rates of temperature rise varying from 20° to 200° C/sec. The variations with time of temperature, elongation, and electrical resistance are outlined.—G. F.

Variations of Transformation Characteristics within Samples of an Alloy Steel. W. Steven and D. R. Thorneycroft. (*J. Iron Steel Inst.*, 1957, Sept., **187,** 15–32). [This issue].

Determination of Residual Austenite in High-Speed Steel by the Magnetic Method. A. I. Gardin. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 303–309). [In Russian]. The

problems associated with the determination of residual austenite in high-speed steels by magnetic methods are critically considered and data obtained for specimens after various heat treatments are presented. Comparative experiments with technical iron and steels of different compositions showed the effects of alloying elements and of tempering at 750° C on magnetic saturation. Volumetric and gravimetric carbide-phase contents for numerous specimens of two high-speed steels in the annealed state and after hardening from temperatures of 1200–1280° C, at temperatures in the range 160–700° C as well as in the hardened state, are shown. Tempering times varied from 0·5 to 10 hr.—S. K.

CORROSION

The Mechanism of Water-Line Corrosion. A. M. Peers. (*Abstracts of Dissertations, University of Cambridge*, 1953–1954, 213–214).

Determination of the Corrosion Properties of Soils. V. S. Artamonov. (*Zavodskaya Laboratoriya*, 1956, **22**, (6), 692–693). [In Russian]. Accounts are given of devices for determining the liability of soils to cause corrosion in metals in contact with them. Both field and laboratory types are described, and some results are presented.—S. K.

The Corrosion of Cargo Ships and its Prevention. H. J. Adams and J. C. Hudson. (*Trans. Inst. Naval Architects*, 1956, **98**, 346–376). A review of both underwater and superstructure corrosion with an account of protective compositions and cathodic protection is given with a section on internal corrosion and an appendix on particular cases. Discussion and reply (365–376).

Reactions on Stainless Steel Surfaces. T. N. Rhodin. (*J. Chim. Phys.*, 1957, **54**, Jan., 72–89). A slightly extended account of the work reported in *Corrosion*, 1956, **12**, Mar., 123–135t, with further discussion.

Apparatus for Determining the Corrosion Aggressiveness of an Atmosphere. N. D. Tomashov, G. K. Berukshtis and A. A. Lokotilov. (*Zavodskaya Laboratoriya*, 1956, **22**, (3), 345–349). [In Russian]. A simple apparatus is described for studying the atmospheric corrosion of metals and comparing the corrosiveness of different atmosphere. The method is based on the creation and study of a macro-model of the corrosion cell which could operate under the atmospheric conditions.—S. K.

The Failure of a Welded Drying Drum by Caustic Embrittlement. G. Dines and E. C. McLean. (*Mech. Eng.*, 1956, **78**, Dec., 1105–1109). A careful metallographic study is reported with a review of the phenomenon.

Investigations of the Thermodynamics and Composition of Wüstite. H.-J. Engell. (*Arch. Eisenhüttenwesen*, 1957, **28**, Feb., 109–115). The Wüstite phase has been determined for the temperature range between 650° and 1000° C, using oxide layers found by oxidation of pure iron in oxygen. The gradient of the iron content of these layers was determined, and the wüstite composition at the iron-wüstite and wüstite-magnetite phase boundaries was used to define the wüstite area. The results agreed well with those of F. Marion.

Interactions Between Solid and Liquid Metals and Alloys. V. W. Eldred. (*Abstracts of Dissertations, University of Cambridge*, 1953–1954, 205–206). Ferrous and non-ferrous metals in contact with liquid Bi, Cd, Pb, Hg, K, Na, Sn, and Zn up to 550° C were examined.

Accelerated Testing of Metallic Surfaces. W. D. McMaster. (*Metal Finishing*, 1956, **54**, Nov., 48–51, 55). A review of the salt spray test and its modifications is given. The addition of sufficient acetic acid to produce a pH of 3·2 in the 20% NaCl solution is considered to give more reliable results.

The Mechanism of Some Methods of Preventing Corrosion by Air-Dried Coatings. D. Van Rooyen. (*Abstracts of Dissertations, University of Cambridge*, 1953–1954, 214–215). The action of metal linoleates and salts of other organic acids was investigated. A mechanism of inhibition is advanced. Sprayed Al and polystyrene pigmented with Al was also examined.

New Method of Studying Corrosion Inhibition of Iron with Sodium Silicate. E. F. Duffek and D. S. McKinney. (*J. Electrochem. Soc.*, 1956, **103**, Dec., 645–648). Passivity curves taken on polished mild steel electrodes treated for 24 or 48 hr in aerated solutions of sodium silicate containing up to 3500 p.p.m. SiO_2 were compared with those similarly treated in caustic soda solutions of the same pH. Corrosion was inhibited in solutions containing > 15 p.p.m. SiO_2. The silicate additions had a pronounced effect on polarization and the critical current density was shown to be a function of the corrosion rate for each concentration of sodium silicate and hydroxide.—A. D. H.

The Mechanism and Kinetics of the Action of Pickling Inhibitors for Iron and Steel. R. D. Holliday. (*Abstracts of Dissertations, University of Cambridge*, 1953–1954, 207–208). Thioureas and quinolines were studied.

Corrosion Research Laboratories, 11. Fulmer Research Institute. H. K. Farmery. (*Corrosion Techn.*, 1957, **4**, 125–127). An account of the foundation, functions, facilities and previous and present investigations of the laboratories.

ANALYSIS

Ferrous Metallurgy. H. F. Beeghly. (*Anal. Chem.*, 1957, **29**, Apr. Part II, 638–647). A review of analytical aspects 1954–1956. (181 references).

Photocolorimetric Determination of Phosphorus in Heat-Resisting Steels. E. A. Nechaeva and E. S. Lapidus. (*Zavodskaya Laboratoriya*, 1956, **22**, (4), 418). [In Russian]. A brief account is given of a photocolorimetric method for phosphorus determinations in heat-resisting steels containing 0·015–0·035% P with an accuracy of $\pm$ 0·002%. A determination takes 2 hr.—S. K.

Sulphur Method for Determining Oxide Oxygen in Metals. A. K. Babko, K. E. Kleĭner, and L. V. Markova. (*Zavodskaya Laboratoriya*, 1956, **22**, (6), 640–645). [In Russian]. The application of the sulphur method to the determination of oxygen in a series of metal oxides, including those of iron and manganese, is described. The method is based on the combination of the oxide oxygen with sulphur to form sulphur dioxide which is determined iodimetrically. The metal is converted to the sulphide. Reaction of sulphur with Fe_2O_3 was found to be almost complete at 700° C, the rate at 1000° C being appreciably faster; for Mn_2O_3 the corresponding temperatures are 500 and 900° C. The experimental blank determines the minimal quantity of oxygen which can be dealt with.—S. K.

Taking Samples for Determining the Hydrogen Content of Steel. A. N. Morozov, D. Ya. Povolotskiĭ and V. F. Isaev. (*Zavodskaya Laboratoriya*, 1956, **22**, (7) 867–869). [In Russian]. A sampling method is described which is said to enable the true hydrogen content of rolled products to be determined. A special hollow drill is used to obtain a sample along the centre of the side face of the material. The tool rotation rate is restricted to 32 r.p.m. to avoid heating the sample, the drilling of blooms 250 mm in section taking about three hours. Samples were stored in solid carbon dioxide till analysed. Results obtained for two steels are tabulated.—S. K.

Decomposition of Chrome Iron Ore and the Photocolorimetric Determination of Chromium with Trilon B. Yu. I. Usatenko and E. A. Klimovich. (*Zavodskaya Laboratoriya*, 1956, **22**, (3), 279–282). [In Russian]. The influence of various factors on the decomposition of chromite by fusion with flux and treatment with acids and on the subsequent colorimetric determination of chromium have been studied. Analytical procedures are given.—S. K.

Detection of Traces of Iron. F. Feigl and A. Caldas. (*Anal. Chem.*, 1957, **29**, Apr. Part 1, 580–582). Alumina is used as collector precipitate and iron determined with 2:2-dipyridyl or 1:10-phenathroline in thioglycolic acid.

Determining Iron in Chromium Plating Solutions. H. W. Dettner. (*Metal Finishing*, 1957, **55**, Feb., 67). A rapid method for the determination of the iron content of chromium plating solutions using chelating agents—EOTA and 10% disodium pyrocatechol as indicator is given.—A. D. H.

Analysis of Phosphating Solutions. Colorimetric Determination of Nitrate. L. O. Gilbert. (*Metal Finishing*, 1957, **55**, Apr., 66–67).

Spectrophotometric Determination of Iron with 2-Fluorobenzoic acid. E. B. Buchanan, jun. and W. Wagner. (*Anal. chem.*, 1957, **29**, May, 754–756).

Infrared Analysis. N. W. Hartz. (*Mech. Eng.*, 1956, **78**, Nov., 1028–1030). Types and their operation are reviewed.

Methods of Introducing Powders into the Arc in Spectrum Analysis. N. N. Semenov. (*Zavodskaya Laboratoriya*, 1956, **22**, (4), 457–462). [In Russian]. A number of new methods for introducing the powdered sample through a channel in the positive electrode into the spectrum analysis arc are

described, in which the vaporization rate is controlled. The simultaneous introduction of a small quantity of nitrogen has a stabilizing effect.—S. K.

Use of the Carbometer for the Rapid Determination of Carbon during the Production of O.H. Steel. G. F. Chub, I. N. Treiger, A. P. Savranskaya and G. A. Babich. (*Zavodskaya Laboratoriya*, 1956, **22,** (4), 391–397). [In Russian]. A method of carbon determination sufficiently rapid for following the course of the O.H. process is described. It is based on the use of a magnetic permeability instrument (carbometer) requiring samples in the form of rods 120 mm long and 12·90 ± 0·01 mm. in diameter. The cast sample is first dealt with by the instrument, crushed and examined for pores and slag inclusions. If these are at a sufficiently low concentration the result is accepted and manganese is determined steeloscopically, the whole procedure taking 2–3 min. The results are radioed to the O.H. shop.—S. K.

Spectrographic Determination of Lead in Leaded Steel. J. E. Paterson. (*Anal. Chem.*, 1957, **29,** Apr. Part 1, 526–527).

Spectrum Method for the Determination of Aluminium and Silicon in Iron Ore. V. S. Komissarenko. (*Zavodskaya Laboratoriya*, 1956, **22,** (4), 453–454). [In Russian]. A brief account is given of the satisfactory application of the three-standards spectrum analysis technique in the determination of Al (0·047–0·206% Al) and Si (0·09–2·09% Si) in Krivoi-Rog iron ore concentrates.—S. K.

Determination of the Percentage Content of Iron Oxides in Their Mixtures from X-Ray Structural Analysis Data. E. O. Shvaĭkovskaya. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 316–317). [In Russian]. An X-ray method is briefly described by which the percentages of Fe_2O_3 and Fe_3O_4 can be determined with an error of about 1% in mixtures of these oxides.—S. K.

Qualitative and Quantitative. Analysis of the Surface of an Alloy by Means of X-Ray Fluorescence. C. Sautier (*Rev. Mét.*, 1957, **54,** Jan., 1–8). The theoretical principles of the method are first described. The sample is irradiated by a high intensity X-ray beam and the fluorescent radiation produced is analysed with a quartz plate. The method is very rapid in operation. The error involved in quantitative analysis is examined. (25 references).—B. G. B.

The Application of Activation Analysis to Metallurgy. E. Broda. (*Berg- u. Hüttenmänn. Monatsh.*, 1956, **101,** Nov., 228–232). The author gives an introduction to activation analysis and quotes several examples, together with the limits of detection. He mentions the determination of Fe in Co and of C and N in iron. 10^{-4}% C can be estimated by this method.—T. G.

Radioisotopes in Metallurgical Research and Industry. T. Bernert. (*Berg- u. Hüttenmänn. Monatsh.*, 1956, **101,** Nov., 213–219). This is a review based mainly on English and American publications dealing with: radioisotopes as tracers, diffusion and self-diffusion, autoradiographic methods for the study of microstructures, wear, refining of aluminium, process control, and thickness measurement.—T. G.

Examples of the Application of Radioisotopes to Research in the Iron and Steel Industry. H. Krainer. (*Berg- u. Hüttenmänn. Monatsh.*, 1956, **101,** Nov., 246–255). The author reviews γ-radiography in general and discusses the main γ-ray sources such as ^{192}Ir, ^{137}Cs, and ^{60}Co. He then describes autoradiographic experiments with ^{32}P for detecting phosphorus segregation in steel, the diffusion of P during annealing, and its correlation with microhardness. The author concludes with reports of studies on machining with radioactive tool tips.—T. G.

Radon and Autoradiographic Methods in Metallurgical Research and Industry. G. Glawitsch and G. F. Hüttig. (*Berg- u. Hüttenmänn. Monatsh.*, 1956, **101,** Nov., 232–238). The authors explain the radon method and describe Zimens' apparatus for detecting radon quantitatively. They quote as an example phenomena occurring during the sintering of copper powder. They also describe autoradiographic methods and their sensitivity, and compare conventional methods and autoradiography in the study of microstructures, e.g. on a silver–bismuth alloy. (10 ref.).—T. G.

Radioactive Method of Marking Steel Rolled Products. V. V. Kŕyzhanovskiĭ, I. I. Saf'yants, A. D. Tumul'kan and V. A. Yanushkovskiĭ. (*Zavodskaya Laboratoriya*, 1956, **22,** (3), 297–302). [In Russian]. The use of a radioactive isotope for marking coils in cold rolling to indicate the type of steel and the detecting apparatus are described. ^{32}P is deposited automatically by sparking from an electrode in a special vibrator installation to form a pattern characterizing the steel. The pattern is registered by a device based on halogen counters which can deal with strip speeds up to 300 m/min and over. Circuit diagrams for the marking and registering devices are given. The technique is widely applicable.

Instrument for Automatically Recording Radioactive Radiation. V. N. Afanas'ev. (*Zavodskaya Laboratoriya*, 1956, **22,** (7), 862–866). [In Russian]. Variants of an instrument with which both weak and strong radiation fluxes can be recorded are described. The instrument can be used either to measure a changing flux from a single source or to compare fluxes from different sources.—S. K.

INDUSTRIAL USES AND APPLICATIONS

Steam Piping Materials for High Temperature Service. H. S. Blumberg. (*Mat. Methods*, 1957, **45,** Mar., 126–129). Steels used at present and other promising compositions are given and properties discussed. A chart is given.

Metals for Hot Aircraft Structures—Today and Tomorrow. (*Steel*, 1957, **140,** Mar. 11, 154–158). When planes are designed for speeds of the order of Mach 4, the metals used must stand the high outer skin temperatures generated at such speeds. Details are given of the progress made in this direction in the field of stainless steels, hot work die steels, titanium, and high-temperature alloys—G. F.

Bearings for Tough Jobs. Difficult Environments. (*Steel*, 1957, **140,** Apr. 8, 114–115). Ball bearing and separator materials are reviewed and their properties tabulated. Non-ferrous metals, sintered carbides and cermets are included., **High Temperatures.** (116)—Materials, including retainers seals and lubricants are reviewed with regard to service temperature. These are tabulated from the range − 67− + 250° F to 600–1000° F, the latter for low speeds only. **Nuclear Reactors.** (118). A few stainless steels are included with uses indicated. Water lubrication or no lubrication is used.

Steel's Role in Nuclear Engineering. C. L. Huston, jun. (*Mech. Eng.*, 1956, **78,** Apr., 329–330).

Selection and Application of Spring Materials. H. C. R. Carlson. (*Mech. Eng.*, 1956, **78,** Apr., 331–334). Properties of suitable alloys are tabulated.

HISTORICAL

Sven Rinman: A Renowned Metallurgist. E. H. Schulz. (*Stahl u. Eisen*, 1957, **77,** Feb. 21, 221–223). An appreciation of Sven Rinman, the Swedish metallurgist who lived from 1720 to 1792. He was a consultant to the Jernkontoret.

Adolf Ledebur 1837–1906. E. N. Simons. (*Brit. Steelmaker*, 1957, **23,** Apr., 110–111). A biography.

ECONOMICS AND STATISTICS

Development and Growth of the Australian Steel Industry. (*Engineer*, 1957, **203,** Mar. 29, 501–502).

Fluctuations in Stocks: A Nineteenth-Century Case Study. R. H. Campbell. (*Oxford Economic Papers*, 1957, **9,** Feb. 41–55, reprint). The Scottish pig-iron trade of the 19th century is examined when large stocks were carried, made possible by the Glasgow Market and the system of storing iron by independent storekeepers. The study covers 1845–1873 when the system changed. The study was made as a contribution to economic theory on the effects of the holding of large stocks, though other factors tend to obscure this feature.

MISCELLANEOUS

Factors Influencing the Dynamic Behaviour of Tall Stacks Under the Action of Wind. M. S. Ozker and J. O. Smith (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** Aug., 1381–1391). A best procedure employed to determine the internal damping in stack structures is described and some test results presented.—D. H.

Percolation Leaching of Manganese Ores with Sulphur Dioxide. F. N. Bender and C. Rampacek. (*U.S. Bur. Mines Rept. Invest.*, 1957, No. 5323, Mar., pp. 20).

Tungsten Deposits of the Hyder District, Alaska. F. M. Byers, jun. and C. L. Sainsbury. (*U.S. Geol. Survey Bull.*, 1956, No. 1024-F, pp. 123–140).

Tungsten Milling and Current Metallurgy of Canadian Exploration Limited. R. J. McLeod. (*Canad. Min. Met. Bull.*, 1957, **50**, Mar., 137–142). Ore treatment and concentration are described.

Bibliography of Zirconium. E. Abshire. (*U.S. Bur. Mines, Inf. Circ.*, 7771, 1957, March, pp. 281).

Ventilation in Iron and Steel Works. M. Hansen and H. Spitzer. (*Stahl u. Eisen*, 1957, **77**, Feb. 21, 204–215). The principles of ventilation of various types of workshop and plants in iron and steel works are discussed and a number of examples of good ventilation quoted. Cases of ventilation by natural convection and by forced-air circulation where necessary are demonstrated.—T. G.

Errata Vol. 184

P.105, Col. 2. Line 18 from bottom.
For " Zel'pet " *read* " Zel'bet ".
P. 107, Col. 2. Line 6 from bottom.
For " MacMillan " *read* " McMillan ".
P. 234, Col. 1. Line 8.
For " Epelborn " *read* " Epelboin ".
P. 364, Col. 2, Line 11.
For " D.I. Medovar " *read* " B. I. Medovar ".
P. 371, Col. 2, Line 6 from bottom.
For " Y. Ishizaki " *read* " T. Ishizaki ".
P. 371, Col. 2, Line 23 from bottom.
For " Ishizahi " *read* " Ishizaki ".

BOOK NOTICES

BASHFORTH, G. REGINALD. " *The Manufacture of Iron and Steel.*" Volume One. " *Iron Production.*" Second edition, revised. 8vo, pp. xi + 306. Illustrated. London, 1957: Chapman & Hall, Ltd. (Price 45*s.*).

The second edition of this book is a third as big again as the first and is printed on better paper, but the price is more than doubled. There is evidence of revision all the way through the book, and details have been incorporated or references made to most of the important modern developments which are too numerous to specify here, although concentration processes for ores are still not fully covered.

The author's own diagrams are usually clear and simple, but some of those taken from other sources are too complex and too fine in scale to be of much value. Also, certain exterior views of equipment are of limited value, and as illustrations are old-fashioned in appearance. The text is expressed clearly, although it is sometimes inclined to be superficial, and in places reads too much like a review.

The book remains a useful and comprehensive account of iron manufacture, but with no deep consideration of fundamental chemistry. It has been noticeably revised and expanded.—A. R. BAILEY.

BRITISH ELECTRICAL DEVELOPMENT ASSOCIATION. " *Induction and Dielectric Heating.*" (Electricity and Productivity Series, No. 6). 8vo, pp. xv + 191. Illustrated. London [1957]: The Association.

This book, intended for management executives, both technical and non-technical, gives brief, but adequate explanations of induction and dielectric heating, and then describes and illustrates numerous applications. Most of the material on induction heating deals with the melting and heat-treatment of metals and occupies two-thirds of the book; that on dielectric heating is of lesser metallurgical interest, core-drying being the only metallurgical example. Nevertheless, the book will be of much value in the metal trades, and fulfils very well the general purpose of the series, " Electricity and Productivity," earlier volumes of which have already been reviewed in this Journal.—J. P. S.

GARSIDE, JAMES E. " *Process and Physical Metallurgy.*" Second edition, revised. 8vo, pp. xx + 593. Illustrated. London, 1957: Charles Griffin & Co., Ltd. (Price 54*s.*).

As the title indicates, this book covers a wide field, the main features of which were outlined in the review of the first edition (this *Journal*, July, 1949, p. 375). However, as pointed out there, certain important omissions were noticeable, namely, details of fatigue, creep and the mechanical testing of metals (and others, such as brittle fracture, may be cited). These have not been remedied, although two new chapters, on powder metallurgy and corrosion, have been added. The latter widen the scope and improve the book, but one wonders why such a specialized process as powder metallurgy should be accorded more than twice the space given to the whole of mechanical working.

With regard to the rest of the text, although this has been revised, most of the points of criticism made in the first review can still be applied. In addition, it should be noted that dislocations are not even mentioned in the rather uninspired section on general physical metallurgy. The poor quality of the photomicrographs has also been mentioned earlier, but one must protest here against the horrible optical micrograph of pearlite on p. 173, which should never have been offered for comparison with an electron micrograph. And among other minor points, what makes the author suppose (p. 399) that α–β masses are the only ones liable to embrittlement by molten solders, and where is his evidence for stating on the same page that sea water causes season cracking of α-brass Further, he should qualify his remarks on the brittleness of α-brass (p. 397), and he would do well (p. 391) to warn against bismuth contents in copper of much lower values than 0·02%.

There is a lot of useful information in this book, especially, for example, on fuels and refractories, pyrometry, and industrial processes and alloys, but certain of the chapters, such as the first one on ores and ore-dressing, are superficial in treatment, and there are numreous faults.
A. R. BAILEY

KLAS, HEINRICH, and HEINRICH STEINRATH. " *Die Korrosion des Eisens und ihre Verhütung.*" (Stahleisen-Bücher, Band 13). 8vo, pp. xii + 504. Illustrated. Düsseldorf, 1956: Verlag Stahleisen m.b.H. (Price DM. 55.-).

The numbers of papers on corrosion and related topics appearing annually runs into several thousand so that it is impossible, even for the specialist, to keep abreast of the more recent advances in this very important field. This book on the corrosion of iron and steel is therefore very welcome, since ferrous materials are still those most widely used for constructional purposes.

The subject has been divided by the authors into seven main sections: theoretical basis, the properties of pure iron and ferrous materials, the corrosion of iron and steel as a technical problem, corrosion testing, corrosion prevention by selection of materials, active corrosion protection, and passive corrosion protection. The theoretical basis has been treated in a simple straightforward manner while giving adequate place to modern concepts such as the Pourbaix diagram. The various types of corrosion are enumerated and illustrated by excellent photographs. The section on underground corrosion is very good, particular attention being paid to the classification of soils. A short section on corrosion in the petroleum industry is given.

The section on active corrosion prevention includes treatment of drinking water, the use of inhibitors, treatment of boiler feed waters and a very good review of the practical application of cathodic protection.

Nearly half the book is devoted to passive corrosion protection including degreasing, rust and scale removal, surface treatment, metallic coatings (zinc, cadmium, aluminium, chromium, tin, lead, nickel), and organic coatings.

The format is very attractive and the diagrams are excellent. The style is good and very readable. Most of the 1,344 references, which are grouped according to the chapters, are to German work. It should be of interest not only to workers in corrosion science but also to engineers in designing equipment as well as in combating corrosion in the field. It can be recommended both for study and for reference.—G. BUTLER.

P. JUBB, B.Sc., A.Met.

MR. JUBB, who is a native of Sheffield, has spent all his working life with the Firth-Brown organization. From 1926, when he was 17, he worked in the Brown-Firth Research Laboratories until 1933, when he was appointed manager of the armour-plate heat-treatment department of Thos. Firth and John Brown Ltd. He remained there during the rearmament period and the War. In 1945, when the demand for armour plate slackened, he returned to the Brown-Firth Research Laboratories and has been there ever since, engaged in general metallurgical research work, principally with stainless and other alloy steels. He has served on several B.I.S.R.A. committees; at present he is a member of the Ingot Moulds and Tool Steels Committees, and he was for 13 years secretary of the old Pyrometry Sub-Committee of the Ingots Committee. He is an Associate in Metallurgy of Sheffield University and a B.Sc. of London University; both these qualifications were obtained as a result of evening studies. He was awarded the Mappin Medal by Sheffield University when he obtained the former qualification.

Mr. Jubb joined the Sheffield Metallurgical Association in 1932, and served as secretary from 1947 to 1949. He has always taken a keen interest in both technical and social activities of the Association. He was elected President for the 1957–1958 session, and as such serves as an Honorary Member of Council of the Iron and Steel Institute during his term of office.

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Honorary Member of Council, 1957–1958